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Environmental planning of large-scale water projects: The Three Gorges Dam case, China

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Environmental Planning of Large-Scale Water Projects:

the Three Gorges Dam Case, China

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ABSTRACT

Controversy over the construction of the Three Gorges Dam across the Yangtze River in China is an on-going national issue. Proposals have been advanced by numerous disciplinary research teams to identify the environmental consequences of the project development. However, whether the project will benefit or damage the overall environment still remains in question.

No matter which one of the four storage schemes is going to be put into operation, the human, economic, biological, and physical environmental alterations will have no equal in the our contemporary world and probably even for some time in the future. Above all, flood control, hydro-electricity production and waterway improvement are the beneficial consequences, while population displacement, destruction of fish habitat, reservoir sedimentation, and coastal degradation are the adverse effects. Among all of these, flood release, power generation, and inhabitant resettlement are the most critical concerns of the project. Geographically, the project will be of advantage to the area downstream of the dam.

Through application of an Environmental Evaluation System *(EES)*, it is revealed that (1) the 150-m Storage Scheme is the best one among the four alternatives, (2) each of the four is able to create more beneficial impacts than adverse ones on the environment, and (3) between 150 m and 180 m, the lower the normal water-level behind the dam the greater the benefit to the environment. The development of the 150-m Project is therefore shown to be advisable.

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CHAPTER I

INTRODUCTION

> "There is nothing new about the development of river basins, nor about the construction of dams in such development. Both activities have been going on for at least 9,000 years. What is new, however, is the acceleration in the rate of dam building and the complexity of the task of the river basin development."
>
> C. Elliott, 1981

The Yangtze River, like the Amazon and the Nile, is one of the largest rivers on the earth. Research concerned with large-scale water development on the Yangtze has been going on for a long time. In fact, the study of developing hydro-electric power on the Yangtze started in the first decades of the century and continued up to the present. As early as in 1923, report on the necessity of damming the blue river at the Three Gorges was submitted to the president of the Young Republic of China, Sun Yat-sen. He then ordered the first studies. In particular, during the last several years a good deal of research has been conducted in terms of impacts on human, economic, biological, and physical aspects of the environment. However, most of the studies, which focused only on one of the issues rather than the whole and which made many qualitative environmental impact estimates separately, cannot identify the quantitative changes of environmental quality at all. Furthermore, the environmental impacts of the Three Gorges project, especially the major adverse impacts, still have need of further study.

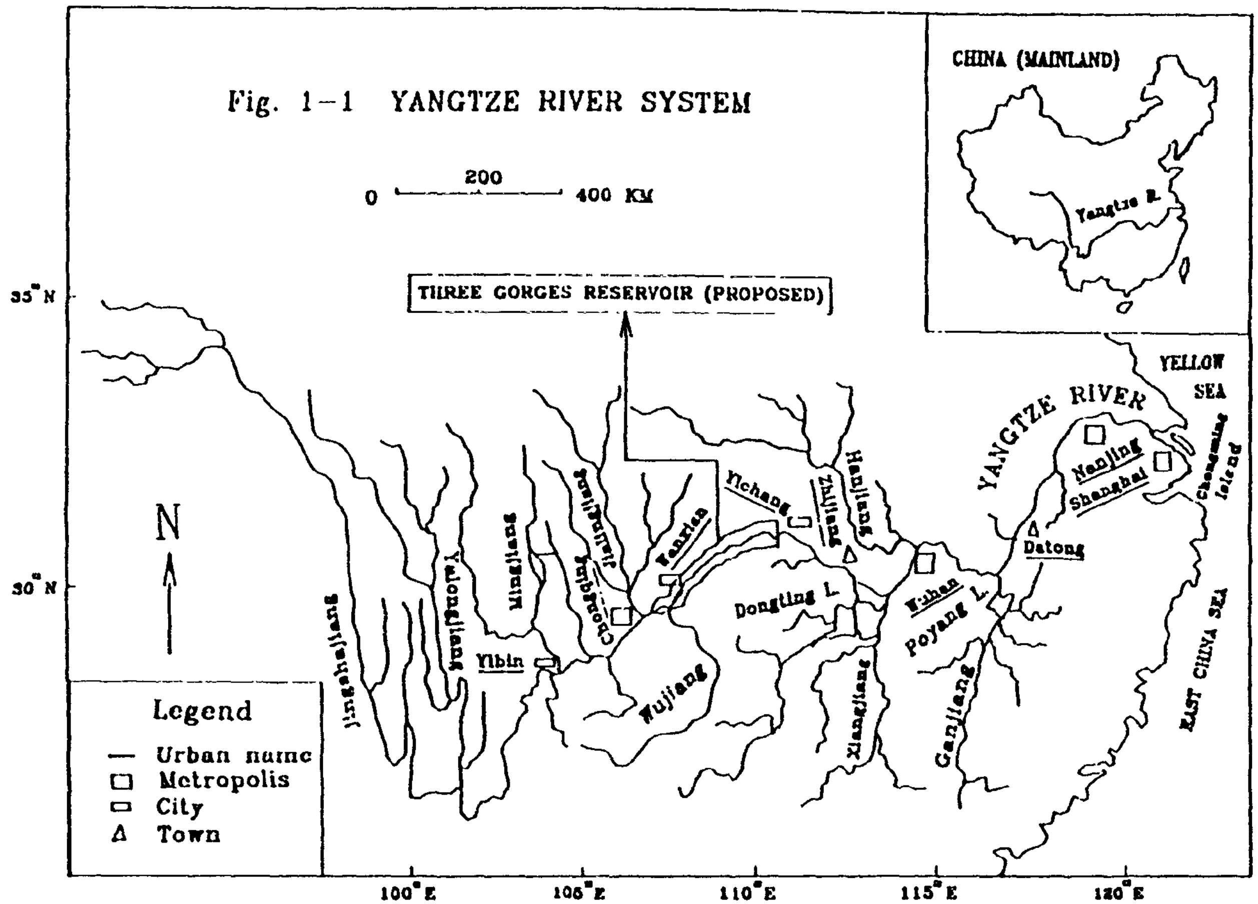


Fig. 1-1 YANGTZE RIVER SYSTEM

1.1 BACKGROUND

No two dams are exactly alike; nor have they necessarily been built for the same reason. Dams are too often built to satisfy one or more primary growth objectives of a region or nation. The Three Gorges Dam, a multi-objective project, is of unusual importance for the entire population of the Yangtze River Basin.

1.1.1 The Yangtze River

The Yangtze (Fig. 1-1) takes its beginning in the southeastern slope of Geladandong (6,621 m a.s.l.), the highest peak of the Tanggula Range, Qing-Tibet Plateau, and flows through China's ten-province-ranked districts of Tibet,[1] Qinghai, Sichuan, Yunnan, Hubei, Hunan, Jiangxi, Anhui, Jiangsu and Shanghai.[2] Finally it enters the East China Sea. It is 6,380 km long and its basin area is 1,808,500 km^2 (i.e. one-fifth of the territory of China with a population of more than 300×10^6 persons). In both of discharge and length of the river, the Yangtze is the third largest river in the world.

The Yangtze in its upper section, especially the part known as Jingshajiang, is a typical mountain river. The source area of the river lies at an altitude of more than 6,000 m a.s.l., and at Pingshan some 2,500 km away from the source, the absolute river level drops to 305 m, i.e., the grade is equal on the average to 2‰. The character of the river bed is marked by the unevenness of the drop and the significant breaks in the

1. Special Municipality.
2. Autonomous Region.

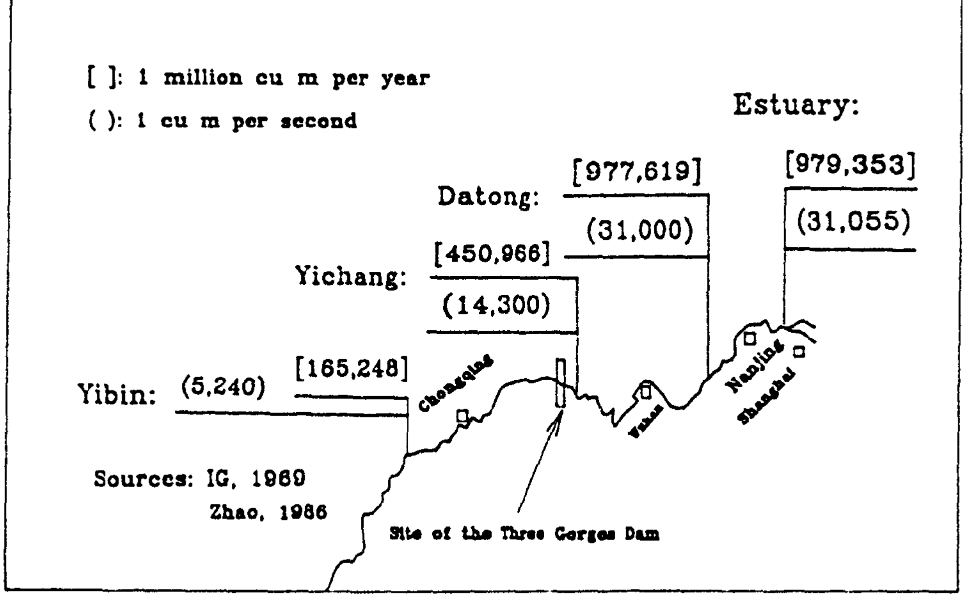
long profile. It has all the features of the hydrological regime proper to mountain rivers. It reacts sharply to the change in the climate and possesses deeply-incut steep channels which are capable of handling enormous amounts of water.

In its course across the Sichuan depression bordered by high mountains, the descent decreases and the river current is not as rapid, and the river changes gradually into a long profile with a broader valley. The mean grade of the channel is 0.12‰ and only in the steepest parts reaches 0.2‰. Rapids are encountered predominantly on the section between Chongqing and Yichang, where over a distance of 660 km there are 25 rapids and 139 dangerous shoals impeding navigation. Here, the numerous gorges cut through the mountains in depth from several tens to several hundreds of metres. Of particular renown are the Three Gorges, Qutang, Wu and Xiling, lying between Fengjie and Yichang. These Gorges are more than 90 km long and follow one another closely. The river there becomes less than 200 metres wide and is squeezed in between almost sheer walls up to 500-600 metres above the water. With the potential hydro-power of 10^6 kw, the Three Gorges have no equal in China (IG, 1969, p. 147-156).

Only below Yichang, the inception of its middle course, does the Yangtze all at once cease the deep incutting. It enters the depression of Central China, and all the way down to the mouth with a slight grade of only 0.02-0.008‰. Its broad alluvial plain has clearly expressed, developed terraces. Over this entire extent of about 1,800 km the river is held back by large levees (on the average 7-8 metres high and in certain areas reaching 16 metres), which protect an area of more than 248,000 km^2 from inundation. While the water level during the low period does not exceed that of the surrounding flood plain, during the flood period it rises above the plain and threatens to break the levees. The river meanders greatly and is connected by channels to a system of lakes, which have a strong influence upon regulating the runoff of the Yangtze. The delta with an area of 80,000 km^2 (about 350 km long, 80 km wide close to the coast) begins at Nanjing. Immediately after passing by Shanghai, the Yangtze flows into the sea by the relatively recent Chongming Island.

The basin of the Yangtze lies in the humid-monsoon climatic area. Each year it receives on the average up to 995.3-1105.9 mm of precipitation. The mean annual runoff and discharge over many years increase considerably from the upper section to the lower section (Fig. 1-2), because the river there receives the largest tributaries including Minjiang, Jialingjiang, Wujiang and Hanshui.

Fig. 1-2 DISCHARGE OF THE YANGTZE RIVER



The annual discharge changes rapidly, reaching at Datong during the wettest years 93,000 m^3s^{-1} (1954), and dropping to 5,270 m^3s^{-1} in dry years. In the entire Yangtze Basin, the greatest rise in the riverlevel occurs in the summer season, and the greatest drop in the winter season (IG, 1969, p. 147-156).

1.1.2 Need for the Three Gorges Project

In China, the Yangtze River below Yichang is called "the Golden Channel". It connects all cities from Yibin to the river mouth by waterways. The Yangtze Plain covers the extensive valley of the great Chinese river in its middle and lower courses, the most populated and the most developed part of China. From the geographical point of view, it is the Yangtze that has been encouraging the modern civilization development in this valley region.

Perhaps the Yangtze presented the encouragement to growth of the civilization along its banks too much in the last centuries. As a result, population, industry and agriculture increased without proper control, so that the Yangtze no longer supports the area as before. The most remarkable problems are given below.

A. Lack of Electricity Supply. 23 cities including four of the Chinese largest metropolises, Shanghai, Nanjing, Wuhan and Chongqing, are located beside the banks of the Yangtze. This area and even all of the southern part of China are quite poor in energy resources. For instance, in Wuhan with the same population as Montreal's, the factories have to cease production 2-3 times a week to enable others to use electricity.

B. Inadequate Navigation Conditions. The section of waterway between Chongqing and Yichang is the main transportation link connecting the southwestern part of China with the East, but a number of shoals and rapids spread in the channel and hence impede the navigation there. Because of such physical obstacles, heavy ships, which could tackle the problem of recently increasing cargoes, are not able to navigate this section.

C. Destructive Floods. The Yangtze is subject to the threat of inundation in its middle and lower reaches, particularly on the 300-kilometre leg between the towns of Yichang and Changlingji (the inception of the lower reach) and in the region of the mouth of the Hanshui tributary which is located downstream of the Three Gorges. The danger of flooding is due to a number of particular natural conditions of the locale: the low relief, the slight slope of the river beds and the torrential character of the precipitation.

During July-August of 1954, the heaviest flood of the century inundated land of 3.17×10^6 hectares and suffered 19×10^6 inhabitants. Most of Wuhan was covered by the water and Jing-Guang Railway was closed for one hundred days. Since 1954 no crucial projects have been undertaken to prevent the middle and lower reaches of the Yangtze from disastrous floods. It is apparent that a huge population and immense property are at risk of being flooded during the period of high water-level every year.

The first two problems of power shortages and hazardous navigation above could be considered corollaries of the Yangtze's favourable environment, but the last disastrous hazard of the flood should be attributed to the Yangtze alone. Clearly, the issues arising from the Yangtze are extremely severe today. The Yangtze must no longer remain the same and significant adjustments should be made to it as soon as possible. There is no alternative but to take advantage of the presence of the Three

Gorges to build a dam here which could provide sufficient hydro-power and destructive-flood control for the middle and lower reaches of the Yangtze, as well as create suitable navigation conditions for the channel between Chongqing and Yichang.

It is well known that the channel of the Three Gorges is the best place within the Yangtze to build a huge dam. The gorges, deep and narrow, present an upstream reservoir of sufficient dimensions and inflow potentials, thus making this Three Gorges Dam Project feasible and economical. If the water-level behind the dam reaches the height of 180 m a.s.l., the project is conceived 1) to supply China with electric power of $38.1\text{-}89.1\times10^9$ kilowatt-hours annually, 2) to improve the navigation conditions between Chongqing and Yichang throughout by the long reservoir (600-700 km), and 3) to regulate a one-in-a-thousand-year flood below the dam, when combined with the existing protective installations and other emergency installation. At this point, it seems that the Yangtze's Three Gorges Dam is able to promote modern civilization along the river for the future generation.

1.1.3 Resultant Issues of the Man-Made Lake

On the other hand, this man-made lake will impose other problems on the river basin, among which the most serious one is population displacement. This issue is a fundamental barrier to the initiation of the project: "Building the dam is easy, but displacing the people is hard", as a saying goes. The Yangtze hardly offers new support systems to the displaced persons because it is almost exhausted. So far both China's national government and the local government do not have a feasible plan for settling the inhabitants from the proposed reservoir area.

According to the statistics of June 1986, the resident population living in towns and villages of the area to be inundated amounted to 768,000; the cultivated land to be flooded will be 670 km^2, if the waterlevel rises up to 180 m a.s.l. (EOPYR, 1986). Of course, cultural properties such as the historical remains, graveyards and so on, will also be flooded, but they all are much less important concerns.

In addition, this large-scale impoundment of the river will likely produce sudden and dramatic changes in the quantity, timing, and quality of flows within the river downstream. At least, fish species will be adversely affected. However, because the reservoir will be quite narrow: it will add only 330 km^2 of water area to the original river water surface of 340 km^2, it could not result in dramatic effects on the other wildlife of birds, animals etc. Also, the incursion of salt water into the lower reach of the river as a consequence of reduced freshwater discharges will probably occur.

In conclusion, the Three Gorges project will bring prosperity in power supply, flood control and waterway condition improvement to China, but this can be achieved only with a continuum of problems. Such large-scale development of the Yangtze will generate beneficial and adverse impacts on human, economic, biological, physical components of the environment in the river basin. At the present planning stage, the most important tasks are 1) to analyse and estimate the major impacts of the project piece by piece; 2) to evaluate the expected future conditions of environmental quality "without" the proposed project and then "with" the project; and 3) to seek solutions to minimize the adverse impacts on the environment in the future.

1.2 OBJECTIVES

A river basin is a complex of human, economic, biological, and physical systems. River basin development like development in any other setting may have a host of inter-related effects on the environment. River basin development that involves the construction of large dams may have particularly significant and complicated environmental effects. The development must be pursued to meet the basic human needs of the population concerned, to secure better environmental prospects for them, and to minimize the adverse impact. With this in mind, the present study, based on practices in China and in other countries and employing a methodology of an Environmental Evaluation System (EES), aims at the following objectives:

1. Demonstrating the dramatic and far-reaching environmental consequences of impounding the Yangtze.
2. Finding out the difference between the expected conditions of environmental quality "without" the project and then "with" the project.
3. Identifying considerations that are necessary at the preparatory stage as well as the operation stage for dealing with issues arising from the river impoundment.
4. According to the case study of the Three Gorges Project, providing universal insights of potential value for environmental planning of large-scale water resource development projects in the world.

The Yangtze River is one of the world's largest rivers; the Three Gorges Dam will be one of the world's largest dams; and the Yangtze River Basin planning is likely playing a significant role in the development of its valley and surrounding areas. Most importantly, the problems of environmental planning this thesis focuses on are quite common in water resources development. Therefore, it is also hoped that the present study could widen the environmental knowledge and awareness of the world about man-made lakes.

1.3 STRUCTURE

This thesis presents a comprehensive geographical analysis and then an environmental system evaluation of impounded rivers; it seeks to generate an improved understanding of the fate of the river, and of the scale of changes in space and time, after the dam construction. The focus is placed initially on the beneficial and adverse alteration to a river system imposed by the impoundment. The thesis consists of six chapters.

Chapter 2 is devoted to review of the literature. It presents the universal effects of man-made lakes on the human, economic, biological, and physical components of the environment. In particular, two significant events in the modern history of river basin plans, the Tennessee Valley Authority (TVA) and the Aswan High Dam are investigated. Then an overview of recent research on the Three Gorges Project development is considered. Finally an Environmental Evaluation System (EES) for large-scale water resources development is discussed, which establishes the methodological foundation of this study.

Chapter 3 analyses the current conditions of the environment concerned and concentrates on the dominant aspects of the beneficial and adverse impacts of the Three Gorges Project by using the most significant parameter indices. The results generated in this chapter are essential to the following chapter.

Chapter 4, based on chapter 3, transforms the environmental impact estimates into environmental quality and determines the change of the environmental quality after the proposed dam completion. A methodology of the EES is applied in conducting environmental impact analyses, as a backbone of this chapter.

Chapter 5 stresses the overall considerations for controlling and minimizing the adverse impacts of the Three Gorges Project. It presents a number of environmentally-sound measures and solutions required for the future water resources development and the management of the Three Gorges Project.

Chapter 6, the closing part of the work, sums up the case study of the Three Gorges Project, and then discusses whether or not the project should be constructed in the near future.

CHAPTER II

LITERATURE REVIEW

At the world-scale, intensive dam construction continues and the size of man-made lakes increases. The spread of dam-building activity during last few decades dominated water resource planning in impounded river systems. Relatively few learned papers were published on impounded rivers prior to 1960, but there has been a dramatic rise in the number of the citations in the subsequent two decades.

In detail, prior to 1960, the literature was dominated by engineering studies of reservoir sedimentation and channel degradation, which were related to questions of reservoir safety. More than one hundred catastrophic dam failures have been reported since 1930 for USA alone (Greenhalgh, 1980). During the late 1950's and early 1960's, research concerned with the effects of large reservoirs upon river water quality, and the sequences of dams as barriers to fish migrations, became important themes. It is only since the late 1960's that data have been presented to demonstrate the full ramifications of building a large dam upon channel morphology, aquatic plants, planktonic and benthic invertebrate communities, indigenous fish and riparian, wetland, and floodplain habitats (Petts, 1984, p. 10-11). Significantly, in the meantime a large variety of literature has focused on the comprehensive geographical analysis of damming rivers in relation to the human, economic, biological, and physical conditions of the environment. The studies on several large rivers which were dammed and will be dammed have been carried out in different countries. Additionally, a set of methodologies of environmental evaluation systems for water resource planning has been developed by interdisciplinary research teams. A brief look at the literature will be given in the current chapter.

2.1 ENVIRONMENTAL RISKS ARISING FROM MAN-MADE LAKES

Dam construction is conducted initially for the purposes of control of destructive flood, provision of water for domestic and industrial needs, development of aquaculture and irrigation, creation of suitable conditions serving as waterways and generation of hydro-electric power. As a worldwide means of water resources development and management, dam constructio ings prosperity to the country, but with a sequence of environmental hazards within, and along downstream sections as well as upstream simultaneously.

2.1.1 Dam Construction: Human Risks

The formation of a new lake inevitably produces a number of local environmental changes. A few are favorable to the local inhabitants, but most are harmful. For the benefit of the many, people in reservoir areas lose their productive land and are compelled to leave for a new settlement. They are deprived of their immovable property as well as their means of living. Furthermore, dam construction frequently causes changes in the pattern and transmission of human diseases so that the local people will suffer from the spread of water-associated diseases.

A. Inundation of Cultivated Land

It is well known that much of the cultivated land of the world is situated in or near river valleys. The construction of dams across valleys results, of course, in inundation of cultivated land, destruction of property and disruption of support systems behind the structures.

For example, in Ghana the Volta River Reservoir inundates an area of 8,482 km^2, or 3.6% of the surface area of the country. It is 402 km long, and occupies the centre of the riverine system of the country and drains most of its rivers (Kalitsi, 1973). Another large man-made lake in Africa, the Aswan Reservoir, has a surface area of 6,276 km^2 and a length of 480 km. Men who had lived in the reservoir areas generation after generation had to leave the areas before they were flooded.

As a result of the creation of the man-made lakes, a great number of people, in the public interest, were ousted from their familiar surroundings. The numbers of persons displaced were: Lake Kariba (Zambia and Southern Rhodesia) 50,000; Volta lake (Ghana) 80,000; Lake Nasser (Egypt and Sudan) 10,000; and Lake Kainji (Nigeria) 42,000. In other continents the figure of 30,000 has been quoted in connection with the Keban Dam in Turkey; for the Sarafov Reservoir on the Volga River 23,000 people were resettled; in India one major project displaced 52,000 in 228 villages; in Thailand the Ubolratana Dam on a Nam Pong tributary affected 30,000. Smaller projects have also uprooted population: 1,131 families were moved in Japan in connection with 43 dams, 2,555 inhabitants were affected by reservoir construction in the Ruhr Valley in Germany, and in the construction of 20 dams in the Tennessee Valley reservoir system over 12,000 families had to be relocated (UNEP, 1977).

B. Suffering of Relocatees

Most of reservoir inhabitants are farmers. Like the other people in the river basin, they are even somewhat prosperous because they are occupying low-lying relatively fertile land. The need for their displacement is a direct consequence of the execution of the dam construction. From a moral point of view, it is the responsibility of the project authorities to ensure that the displacr ,eople are not only provided with suitable compensation for their losses but also assistc_ in every possible way to obtain a new livelihood elsewhere ı fact, this aspect has been either unsatisfactorily dealt with or even completely neglected in some recent big dam projects in less developed countries.

"Project budgets in developing countries normally cover only outlays for construction which is financed for the greater part by donor countries and/or international agencies; outside experts and contractors are engaged to carry out feasibility studies and the planning and execution of the construction work. The usual assumption is that the rehabilitation measures can be left entirely in the hands of the government of the country in which the project is located" (Takes, 1973). In many cases, displaced people suffer from new adverse environment.

In the African experience, resettlement has not been entirely satisfactory because of inaccurate budgeting, inadequate planning and execution of plans. Houses and facilities in new settlements have not always been sufficiently attractive and convenient to be easily acceptable to the displaced persons. In the Volta lake resettlement scheme, for instance, as many as 60% of the resettled people emigrated to live elsewhere along the lake. In some instances, the development of new agricultural systems have been inadequate and the timing of new agriculture projects unsuitable. Food shortages have occurred before the displaced people settled down to farm. Of the displaced people moved to Lisutu under the Kariba resettlement programme a number suffered from hunger and malnutrition because of inadequate planning of the related agricultural programme to provide food for the 1958-1959 rainy season. Uncertainties about land tenure have also been a disturbing factor. At Kariba, disputes occurred between the located persons and their hosts over land tenure; at Volta, the problem was partially solved by purchasing and distributing farming land to relocated persons some years after resettlement (UNEP, 1977).

Another large-river impoundment project in Africa, the Aswan High Dam, brought some suffering to Egyptian Nubians too. In appreciation for Egyptian Nubians' compliance with the national interests implied in the dam's assumed nationwide economic benefits, the Egyptian government committed itself to compensate them in kind by establishing for them a new community. This provided them with far better living facilities and public service, but many Egyptian Nubians remodeled the new houses in the community to approximate their traditional architecture. In this way, they severed their perceived social needs and customs. The government's lack to consider proper rehabilitation for relocatees was an important reason for the Nubians' displeasure with their new living quarters (Fahim, 1981, p. 61).

In Thailand, compensation for flooded properties was made by the dam-building agency, as an integral component of the overall cost of the dam project. Serious problems with the payment of the compensation were delays in payment, and misappropriation in various forms. Survey data indicated that 29% of the households flooded by the Nam Pong project had to leave their homes before receiving their compensation. In the case of Lam Nam Oon, compensation procedures were not complete five years after inundation. In these cases evacuees would have difficulties to re-establish themselves on new farms and in new houses. Besides, since settlement planners have not been able to define clearly the rights of squatters and others relative to the rights of evacuees, squatters have disrupted settlement plans. The first group of evacuees from the Hai Lunag Reservoir area was threatened by armed men during 1974, when the evacuees tried to occupy the land allocated to them by the settlement officials. The problem with squatters at Lam Nam Oon led to the assassination of the settlement supervisor. Settlements intended for evacuees from flooded areas have instead had to serve chiefly the squatters already established on the land who have not needed or wanted to be resettled. Less than a third of families affected by flooding from reservoirs in Thailand have chosen to move to settlements prepared for them (Lightfoot, 1979). The existence of squatters is an important reason for this low proportion.

C. Spread of Diseases

The storage of water in dams to permit perennial irrigation also encourages an increase in the incidence of water-based diseases, since the accumulation of large quantities of water in dams favours intermediate hosts which transmit the diseases. As the United Nations Environment Programme (1977) stated: "...before the Aswan High Dam the Nile River's annual summer flood water produced just enough moisture to plant and harvest one crop...", "... when dams are built, there are fewer flash floods and this results in the more stable water conditions which provide a suitable habitat for the parasite carrying snails and encourage their growth...."

It is presumed that dams could increase the area of irrigated land and men's contact with water; therefore, it is very likely that dams could increase the incidence of schistosomiasia (blood fever). In 1960, Henry Van der Schalie pointed out that there is evidence that the high incidence of human blood fluke may well cancel out the benefits the construction of the Aswan High Dam may yield. Again, in his 1974 article "Aswan Dam revisited", Van der Schalie drew upon surveys conducted by Dazo and Biles in 1972 and concluded that the average prevalence of bilharziasis between Cairo and Aswan had increased seven times, from 5% in 1930 to 35% in 1972. He attributed that increase to the construction of the Aswan High Dam (Fahim, 1981, p. 36).

Onchocerciasis (river blindness) is transmitted in West Africa by *simulium damnosum*, a fly that breeds only in running water. It tends to be hyperendemic around African rivers, and as an example the Niger and Bandama Valleys in the neighbourhood of their dams were seriously affected. Blindness rates up to 9% have been found in villages near the Old Niger, and a check near the Bandama revealed 15% blindness in one unspecified village and 20 blind out of the small but uncensused population of Kossou itself (Waddy, 1973).

Endemic malaria is carried by mosquitoes which have an obligatory dependence on water for breeding. A wide range of ecological niches around standing water and along water courses and canals are suitable habitats for mosquitoes. Malaria still remains the most vicious killer in tropical areas. The concentration of people around dams and irrigation systems makes them liable to infection with *bancrofti filariasia*, which is carried by mosquitoes.

Trypanosomiasis (sleeping sickness) is closely associated with plants growing around dams and irrigation systems. The plants produce a suitable habitat for the tsetse fly which transmits the genus *trypanosoma* to man. In endemic areas, lake basins and water courses favour the spread of *trypansomiasis*.

2.1.2 Dam Construction: Biological Risks

An impoundment causes changes that affect both the water itself and the organisms which it supports. There is a disruption of the interrelationships between biotic communities as the physical and chemical basis of their environment is altered. Thus river impoundments may be destructive to certain kinds of precious wildlife, and beneficial to aquatic weeds.

A. Destruction of Fishes

The large-scale development of water resource projects has produced sudden and dramatic changes within riverine habitats. Indeed, dam construction appears to have had a great impact upon riverine wildlife, in particular upon fish.

The quality of reservoir tailwaters will differ from that of the natural river because the thermal and chemical character of dam-releases will be determined by the limnology of the lake itself. Surface-release reservoirs may act as nutrient traps and heat exporters, while deep-release reservoirs may export nutrients and provide a heat-store. The thermal influences of impoundments have had their most significant effect upon local fish faunas, eliminating many temperature-specific species (Trautman & Gartman, 1974). Species with specific temperature requirements may disappear if they are unable to tolerate the imposed conditions and, even if adults are able to withstand the imposed stress, reproduction will be adversely affected.

Cold-water releases from the high dams of the Colorado River, USA, for example, have resulted in a decline in the native fish abundance (Holden & Stalnaker, 1975). Also, water-chemistry changes can be significant for riverine fish downstream from an impoundment. Nutrient availability may be decreased because of metabolism within the reservoir, and this will be reflected by reduced loads of nitrates, phosphate, and other dissolved elements. Such changes effectively lower the primary productivity of the river.

The physical presence of a dam, acting as a barrier to the migration of some fish species to and from spawning grounds, causes reduction and even extinction of certain fish. Such catastrophic events can occur during low-flow years as a result of four factors: limited over-dam spillage, reduced flow velocities through reservoirs, passage through turbines, and increased predation in the stilling basin below the dam.

For hydro-electric power-dams, mortality resulting from passage through turbines is especially significant, and turbine losses of juveniles of between 10% and 40% have been reported widely (Schoeneman & Junge, 1961; Ebel & Raymond, 1976). Such factors are in addition to the imposed changes of discharge and water quality. Experimentation by Cramer & Oligher (1964) revealed that turbine mortality could fluctuate between 9% and 54%, depending on tailwater levels, turbine types, and operation conditions.

B. Proliferation of Aquatic Weeds

River impoundments can impose a continuum of changes upon the quantity, timing, and quality of flows above large dams. They can enhance the explosive spread of aquatic plants, especially in the case of tropical dams. This is a recurrent problem. Serious weed infestations have caused concern on Kariba, the Brokopondo in Surinam, the Nam Pong in Thailand and on several other large dams in the tropical and subtropical regions (UNEP, 1977).

Whether submerged, floating, rooted or marginal, aquatic weeds are an expensive nuisance. They block and interfere with water flow and the passage of boats, and they compete with fish for space and nutrients. They are believed to increase the rate of evapotranspiration, and they contribute to public health problems by supporting invertebrates such as mosquitoes and aquatic snails, which are vectors and intermediate hosts for disease-causing agents.

2.1.3 Dam Construction: Physical Risks

Physical risks associated with dam construction can extend over a long distance, from a reservoir to the river mouth. When a reservoir is constructed on a stream, all or most of the sediment transported into the reservoir by the stream will be deposited here. Then clear water released through the reservoir will erode the riverbed on its course downstream. If the water in a reservoir serves an irrigation purpose, the reduction of discharge can result in seawater incursion into the river mouth as well as coastal erosion, while waterlogging can occur in irrigated farmland. Furthermore, reservoir filling may induce seismic activities in its neighbourhoods.

A. Upstream Siltation and Downstream Erosion

The completion of a dam impounds not merely water but also suspended materials within the reservoir. This produces imbalances between the sediment input and output both above and below the dam, resulting in siltation upstream and erosion downstream.

Reservoirs can permanently store the entire upstream sediment-load of the drainage basin. As the relatively high-velocity and turbulent water of rivers feeding the lake is transferred into slow-flowing water within the lake basin, its velocity will be reduced again by the backwater effect from the reservoir. Therefore, the sediment is deposited easily. The coarser particles--including the bed material load--settle out to form a delta in the front of the reservoir, while the lighter particles, and especially clays, are distributed further out in the lake, or may be retained in suspension.

For instance, before damming the Nile, the suspended matter passing Aswan ranged between $100\text{-}150\times10^6$ tons per year. During the first years of storage (1964-1967), silt was deposited along the whole length of the reservoir, almost no sediment was discharged from the reservoir, and the siltation resulted in the loss of about $60\times10^6\ m^3$ of its capacity every year (Hafez & Shenouda, 1977). The reduction of reservoir storage capacity by 1% per year has also been observed throughout Europe (Gvelesiani & Shmalkmzel, 1971), the USA (Frickel, 1972), Africa and Asia (Buttling & Shaw, 1973).

The physical effect of a reservoir on the downstream channel is also an important consideration. After most of the sediment load and all of the coarser material was trapped behind the dam, at least during the early years of operation, the clear-water reservoir release will have an unsatisfied transport capacity that it will attempt to satisfy by erosion of the bed and banks downstream. Thus, severe erosion occurs within the downstream channel. Channel degradation and scour can have damaging effects on riverside structures, such as bridges, culverts, road embankments, etc. In West Pakistan, for example, channel degradation has decreased the water-head at diversion structures and reduced the efficiency of irrigation canals (Gill, 1968).

B. Coastal Degradation

The influence of major flow-regulation reservoirs may extend throughout the length of a river to the estuarine and near-shore, coastal zone. The incursion of salt water into lower reaches of rivers, and coastal erosion by ocean currents, are two consequences of reduced or regulated freshwater discharges that have been observed in different countries.

In Egypt, the impoundment of the River Nile in 1964 caused considerable changes of the hydrographic conditions over the continental shelf in the Egyptian Mediterranean coast (Din, 1979). Before the Aswan High Dam was erected, from 18-55×10^9 m^3 of water were transported to the Mediterranean Sea by the Nile annually; the yearly average Nile flood discharge during the period August to September was as much as 34×10^6 m^3 (Fig. 2-1, A). The estuarine circulation pattern during the flood season was a two-layer flow, with Nile water over-passing a subsurface flow of Mediterranean water (Fig. 2-1, B). The natural flood-water spread over the sea as a surface layer, and moved rapidly along the coast to the east; the 39-degree isohaline was 80 km from the shore, with salinity values of less than 30 degrees to about 7-20 km offshore (Fig. 2-1, C). However, the creation of Lake Nasser imposed a major limitation on the Nile discharges (Fig. 2-1, A), augmented by the loss due to evaporation and irrigation, of 60% of the Aswan High Dam release. Subsequently, the one-layer flow-pattern has persisted during most of the year (Fig. 2-1, B), and the surface salinity of the near-shore zone during August and September has generally exceeded 39 degrees (Fig. 2-1, C).

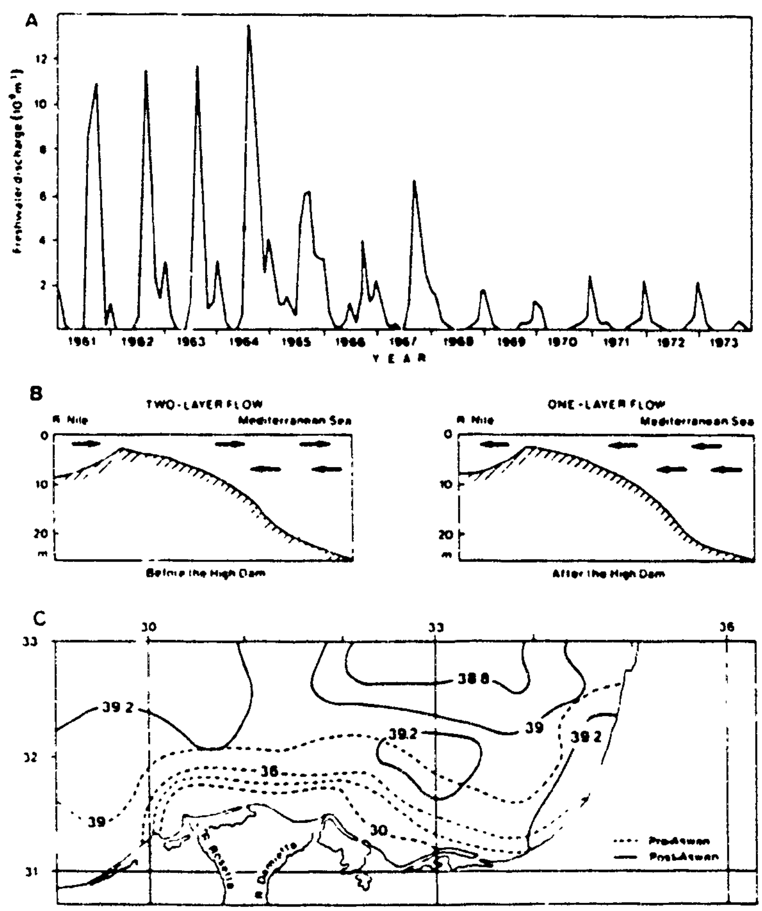


Fig. 2-1 Effects of Nile Regulation by Lake Nasser (A) upon the Flow Circulation (B), and Salinity Distribution (‰) (C), in the South-East Mediterranean Sea (Petts, 1984, p. 49)

Additionally, from 60-80$\times 10^6$ tons of sediments carried by the Nile and discharged into the Mediterranean were deposited near and off the Damiett and Rosetta branches of the Nile, producing the Nile Delta previously. Since 1964, however, almost all the Nile discharge, including sediment, has been impounded in Lake Nasser; the construction of the delta has no longer continued since an imbalance in the near-coast sediment budget has appeared. The deposition helped the delta shores to hold against sea waves and currents. With the disappearance of sediments, the delta shores lost their natural defence line and potentially became exposed to inundation by sea water. The erosion by ocean currents has increased considerably at the two major mouths of the Nile. If no immediate effective measures are taken, the erosion problem could become disastrous in the future (Fahim, 1981, p. 31).

In Canada the regulation of river discharge in the St. Lawrence System is not for irrigation but for power production. The regulation since the turn of the century have caused appreciable changes in dynamics and the physics of the water of the Estuary, Gulf, and adjacent Scotian Shelf. Because fresh water has no longer initiated a circulation in which huge quantities of sea water are transported from the ocean into the Gulf and up the Estuary, reduction in the quantity of sea water entering the system can exceed 150,000 $m^3 s^{-1}$ in the Estuary in the spring, and subsequently grow to 2 or 3 times more in the Gulf at the Cabot Strait in summer. This change decreases the nutrient supply from the deeper water of the ocean to the upper layer and affects the reproduction of many marine species. Along the southern side of the system the surface salinity has increased in the spring at Point des Monts by about 3.5‰ and in summer at Cabot Strait and near Halifax by 1.3‰ and 0.8‰ respectively (Neu, 1975).

C. Waterlogging

With the water trapped behind a dam, agricultural land can become saturated so that the underground water level table will be raised dramatically.

Waterlogging and the incredible rise in underground water levels produce adverse effects on land productivity, buildings, and construction. Waterlogging is a cause of increasing rates of land salinity, which decreases the land's productivity. This problem is especially severe in hot climates because excessive water is shunted onto the land all year round. As the water is drained off improperly, it often sits under the blazing sun, evaporating and depositing salt in the soil. Also, as soon as the underground water comes close to a building's foundation, the construction will suffer from decay due to humidity and possibly collapse in the long run if no immediate remedies are undertaken.

In Egypt, the threat of waterlogging became apparent a few years after the Aswan High Dam was completed. The 15-metre underground water level rapidly rose to only 3 metres on the average. In Cairo, for example, the ground water lies only 81 cm below the surface. A government commission's report (1977) described the waterlogging as largely traceable to delay in implementing drainage schemes, to the wasteful use of irrigation water, and finally to the system of perennial irrigation (Fahim, 1981, p. 31-32).

D. Reservoir Seismicity

Last but not least on the list of the risks of dam construction are earthquakes induced by reservoir filling. Usually, the best place to build a dam is in a deep, narrow gorge with an upstream reservoir of sufficient dimensions and inflow potential to make such a project feasible and economical. These optimum areas are often also situated where past tectonic activity has been present to create the desired deep, narrow gorge, which is associated with faulted structures and concomitant earthquakes. A globally-known example is the destructive earthquake of December 10, 1967, on the Indian Peninsula. It occurred following the impounding of the reservoir in 1962. Its epicenter coincided with Koyna Dam.

Rothé (1973) noted that faults may play a part in the seismicity of the following processes: 1) direct effect along the pre-existing fault plane of shear forces caused by the over-load brought on by the water in the reservoir; 2) indirect effect of the added forces that liberate orogenic tensions of much greater strength; and 3) increase in the interstitial fluid pressure in the blocks of the underlying beds.

It is recognized that filling a reservoir could trigger an earthquake. Several factors may be considered to explain the association of earthquakes with the impounding of water in large reservoirs. The rising water level in a reservoir may change the field of effective stresses in the rock mass as a result of the increase in the pore pressures, and failure may occur. This change will take place especially along joints, faults, or other weaknesses, and thus will allow flow of the pore fluid. As a result of the increase of pore pressures the normal effective stresses decrease, and this decrease may trigger earthquakes. The frequency of the shocks seems to depend on: rate of increase of water, duration of loading, maximum level achieved, and duration for which the high level is maintained. In addition, the height of the water column appears to play a more important role than the surface area or the total volume of the reservoir (Mickey, 1973); seismic activity is particularly pronounced where the depth of the reservoir surpasses 100 metres (Rothé, 1973).

Man, building a dam across a river to create an impoundment, brings prosperity to himself, but at a continuum of risks. To focus only on the risks is to view river impoundments negatively, but it does provide for more careful water development and management. Obviously, it should be important to consider the consequences of river impoundments and to take a series of relevant measures before initiation of a project.

2.2 TWO GREAT PROJECTS IN THE PAST

Large-scale water resource development projects, in their narrower and more technocratic forms, have been developed in many parts of Asia and Africa for at least nine thousand years. The oldest recorded practice of irrigated agriculture has been traced in Jericho in 7,000 B. C. (Hirsch, 1959). There are also recorded histories of scientific water resources development, including quite sophisticated engineering works for water regulation in China, Egypt, and Iraq, which go back several thousand years. Ancient texts and actual waterwork systems in these countries indicate the remarkable knowledge of the hydrological cycle, the ecological balance between surface and ground water, and engineering and social aspects of irrigation (Saha, 1981).

In Egypt, for instance, an intricate system of basin irrigation involving longitudinal dykes parallel to the main channel of the Nile to regulate flood-water, a network of cross-dykes and canals to conduct flood-water into pre-designated basins, and a diversion channel to the naturally formed Faiyum depression to create a storage-reservoir for excess flood-water for later use, was evolved as early as 3,400 B. C. (Hamdan, 1961). Perennial irrigation was introduced in Egypt by Mohammed Ali Pasha through the building of a system of diversion-barrages in the Nile in the early nineteenth century (Worthington, 1972). By the seventh century A. D., the Chinese had developed a highly sophisticated network of engineering structures for irrigation making balanced use of ground and surface water resources, organized a tightly-knit system of administrative authority to ensure a high state of maintenance of these structures, and perfected a land-use pattern that maximized the use of available irrigation facilities (Jones, 1954).

So far most rivers have been subjected to various physical modifications to ensure their continued and reliable usefulness through dam-construction projects. Among these, the system of dams in the Tennessee Valley and the Aswan High Dam in Egypt are two of the most remarkable events in the modern history of river development.

2.2.1 The Tennessee Valley Authority

The Tennessee Valley Authority (TVA) was created by the American Congress in 1933. In order to develop the Tennessee Valley region as a whole, President Roosevelt submitted the 1933-34 Final Report of his National Planning Board (NPB) to the Congress, requesting the legislation to create the Tennessee Valley Authority (TVA). The act of congress declared the purpose of the TVA to be:

> "To improve the navigability and to provide for the flood control of the Tennessee River, to provide for reforestation and proper use of marginal lands in the Tennessee Valley, to provide for the agricultural and industrial development of the said valley, to provide for national defence by the creation of a corporation for the operation of government properties at and

near Muscle Shoals in the State of Alabama and for other purposes," (Congress, 1935).

As a result of the legislation, 36 major dams were constructed after establishment of the TVA. The TVA system of dams makes the Tennessee River one of the most useful in the world, controlling its floods and turning its main stem into a waterway for barge freight and a vast source of water for many other uses. Power harnessed by the dams marked the start of an electric system that serves some 2.8×10^6 homes, farms, businesses, industries, and other users (Brown, et. al., 1983).

Since its inception, operation of the TVA multi-purpose dam and reservoir system has prevented flood damage that would have amounted to nearly $2.2 billion. At Chattanooga, perennially one of the hardest hit areas, average annual flood losses have been reduced to less than 2% of what would have been suffered from an unregulated river system. Accumulated damages averted at Chattanooga total over $1.9 billion. Elsewhere in the Valley prevented damages are approximately $199 million, and outside the Valley, on the lower Ohio and Mississippi Rivers, prevented losses are nearly $119 million. The total flood control benefit is nearly 10 times the capital investment allocated to flood control (Brown, et. al., 1983)

The true impact of having a reliable navigation waterway is immeasurable. Before the reservoir system, stream depths were extremely variable by season and practical navigation was impossible. The objective of providing adequate depth for navigation from the Ohio River to Knoxville has been attained by regulating releases at dams on the Tennessee River to ensure that levels are not drawn below planned minimum levels. Water levels sufficient to provide a 3.3-m depth for vessels of 2.7-m draft are maintained. The estimated annual "shippers savings" in 1980 was $160 million (Brown et. al., 1983), according to the economic measure of the benefits of the waterway, an estimate of the difference between what shippers paid to move their freight and what they would have to pay by the next most economical means of transportation.

Of all the TVA's present sources of power production, hydro is by far the least expensive. During an average year, hydro-electric generation in the TVA power system amounts to about 18.5×10^9 kilowatt hours (Brown et. al., 1983). Annual power production per person in the TVA was 400 kilowatt hours in 1933, 2,400 kilowatt hours in 1943, and 13,000 kilowatt hours in 1980 (Street, 1981).

Today, because the choice of jobs is greater throughout the region, individual freedom is increased, and a variety of leisure time activities has multiplied. There is more and better fishing, and a vast increase in the enjoyment of water sports. There are sailing regattas and motorboat races on the water that covers land where cotton used to grow. Incomes have risen as impediments to enterprise have been reduced and opportunities expanded. In 1933, the average per capita income in the valley was only 45% of the low figure then prevailing in the nation. Now it hovers around 75% of the much higher national average, an improvement accomplished without discovery of new resources, but through more effective use of the region's basic assets. Today there are prospects for work and satisfactory life in the region, and immigration of the jobless no longer compounds the problems of urban centres in areas earlier industrialized. Many factors contributed to the change; the work of the TVA was one among them (Owen, 1973).

2.2.2 The Aswan High Dam

Another great project in water resources development was the construction of the Aswan High Dam across the Nile at Aswan. Primarily, this project was envisioned as a most suitable means (1) to supply Egypt with water when needed and in the amount required for large-scale agricultural development, and (2) to generate energy that would help promote industrialization. Government reports and publications have always emphasized these as major benefits. In addition, it was also believed that the Aswan project would provide monetary gains by eliminating the potential damage of both low and high floods and ensuring year-round navigation on the Nile, which was always impeded during flood seasons (Fahim, 1981, p. 15). In brief, as the late president Nasser frequently remarked: "In antiquity, we built pyramids for the dead, now we would build new pyramids for the living" (Heikal, 1973).

The Aswan project, as hoped, has provided Egypt with a many benefits (Hafez, 1977):

1. The protection of the country from high and low floods;
2. Security of water supply for agricultural expansion and for industrialization;
3. An increase of electric power, and its availability for domestic and industrial purposes: approximately 53% of the total national annual power requirements comes out of the Aswan High Dam, according to 1974 statistics; the Aswan High Dam has more than doubled available electric power;

4. Creation of a wealth of fish in Lake Nasser, which more than compensates the losses of sardine along the coast;

5. Improved navigation conditions; and

6. Creation of great possibilities for more tourism in the Aswan area.

Simultaneously, the Aswan High Dam has produced some negative effects on Egypt from the upstream to the Mediterranean coast, most of which were not predicted. The most serious effects, as mentioned earlier, and which have attracted much concern, are as follows:

1. Population Displacement: 10,000 people in Egypt and Sudan were relocated from their homelands, now covered by water behind the Aswan High Dam.

2. Siltation in the Lake: the loss of about 60×10^{6} m^{3} of its capacity in every year of the initial operation (1964-1967).

3. Riverbed and Coast Degradation: the riverbed, banks and estuary erosion and seawater incursion.

4. Increase in *Schistosomiasis*: a seven-fold increase observed in average prevalence of *Schistosomiasis* between Cairo and Aswan, from 5% in 1930 to 35% in 1972.

Obviously, unlike projects in the Tennessee Valley, the project on the Nile has brought prosperity to Egypt, but also tremendously adverse impacts.

2.3 THE THREE GORGES DAM IN THE FUTURE

In China there has been a long discussion about the construction of the Three Gorges Project. It has been decided that the dam will be built across the Yangtze River at the end of the Three Gorges (See Fig. 1-1), 620 km downstream of Chongqing and 40 km upstream of Yichang. The dam receives water draining from a catchment basin of 10^6 km^2 (about 56% of the Yangtze River Basin) and equal to 451×10^9 m^3 annually (nearly half the annual runoff of the Yangtze through the mouth). At present, much literature still deals with the environmental planning problems created by the project. The project still seems far from initiation since certain crucial issues remain to be settled.

2.3.1 Four Alternative Schemes

The primary question for the construction of the Three Gorges Project is how high the normal water-level behind the dam will be. Both beneficial and negative effects of the project are directly proportional to the height of the normal water-level, but at differential rates. This requires selecting the most beneficial plan among alternative schemes.

There are two basic limitations to the height of the normal water-level: controlling one-in-a-thousand-year floods requires that the normal water-level not be lower than 150 m; keeping Chongqing from being inundated requires that the normal water-level not be higher than 180 m. Thus, 150-, 160-, 170- and 180-m Storage Schemes are being considered as four typical possibilities. From 150-m Storage to 180-m Storage, hydropower production, capacity for flood control, and population displacement increase gradually. Also, it seems that navigation conditions improve proportionally (Table 2-1).

Table 2-1. Estimated Major Impacts of the Four Selected Storage Schemes for the Three Gorges Project

Four Storage Schemes	One-in-a-thousand-year Floods Regulated (cu. m/s)	Annual Power Production (billion kw)	Reservoir Waterway (km)	Displaced Persons
150-m	71,700	66.7	450-550	330,000
160-m	71,700	73.2	530-600	422,000
170-m	75,700	78.5	550-650	622,000
180-m	76,100	89.1	600-700	768,000

Source: EOPYR, 1986.

As a matter of fact, the maximum navigability improvement is achieved by the 180-m Storage Scheme abruptly rather than gradually, because it can create a reservoir waterway between Chongqing and the dam. Any one of the other three will leave a section of the channel below Chongqing in a natural condition so that heavy ship navigation still remains impossible within this section and along the whole channel between Chongqing and Yichang. Therefore, from the navigability point of view, the 180-m Storage Scheme is essentially different from the other three.

2.3.2 Obstruction

The proposed reservoir area is densely populated. Even the 150-m Storage Scheme will cause about 330,000 persons to be displaced, and the 180-m Storage Scheme will more than double that figure. So far almost no feasible solution is available for population relocation. Therefore attention is given to the 150-m Storage Scheme rather than the 180-m Storage Scheme.

In 1983, based on previous research of different schemes, the feasibility study on the 150-m Storage Scheme was submitted to the State Council for examination and approval. In May 1984, the 150-m Storage Scheme was ratified by the State Council. The primary plan of the 150-m Storage Scheme was completed in May 1985 (EOPYR, 1986). Thus the 150-m Storage Scheme will probably be put into practice in the future, at least meeting the need for one-in-a-thousand-year flood control with a minimum population displacement.

As a matter of fact, cultivated land is insufficient everywhere in China in proportion to the residents concerned. Traditionally, Chinese farmers prefer living in the same place generation after generation to leaving for a new environment, unless much better support systems are provided for them. Even if the 150-m Storage Scheme is carried out, the problem of resettlement will still be enormous. Yao, B. H. (1986), summing up the long-term investigation conducted by the Yangtze Valley Planning Office, presented a solution: "...developing the reservoir region to settle the displaced persons nearby."

2.4 A METHODOLOGY OF EES FOR WATER RESOURCE PLANNING

The environment is a complex system consisting of social, biological, and physical resources. Use of these resources by man has both beneficial and adverse impacts on the environment. Evaluation of these impacts is an important but difficult task. Historically, water resource developers have been unable to adequately measure intangible environmental impacts in terms of cost-benefit analysis, focusing instead only on the dollar value.

In 1973, an environmental evaluation system (EES) for water resource planning was developed as a methodology for conducting environmental analysis by an interdisciplinary research team (Dee et. al., 1973). The EES is based on a hierarchical arrangement of environmental quality indicators, an arrangement that classifies the major areas of environmental concerns into major categories, components, and ultimately into parameters and measurements of environmental quality (Fig. 2-2). The EES provides for environmental impact evaluations in four major categories: ecology, environmental pollution, esthetics, and human interests. These four categories are further broken down into 18 components and finally into 78 parameters (Fig. 2-3).

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                                   ------------------------------------
                                   | TOTALITY OF ENVIRONMENTAL IMPACTS |
                                   ------------------------------------
   GENERAL                            |    |    |    |
Level 1. ...............              |    |    |    |
ENVIRONMENTAL CATEGORIES            [_]  [_]  [_]  [_]
                                          |
   INTERMEDIATE                       -----------
Level 2. ...............              |    |    |
ENVIRONMENTAL COMPONENTS            [_]  [_]  [_]
                                                |
   SPECIFIC                           ------------------------------
Level 3. ...............              |    |    |    |    |    |    |
ENVIRONMENTAL PARAMETERS            [_]  [_]  [_]  [_]  [_]  [_]  [_
                                                                |
   MOST SPECIFIC (DATA)                                   -----------
Level 4. ....................................            |    |    |
ENVIRONMENTAL MEASUREMENTS                               [_]  [_]  [_]
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Fig. 2-2 Hierarchical Structure of the EES, after Dee et. al., 1973

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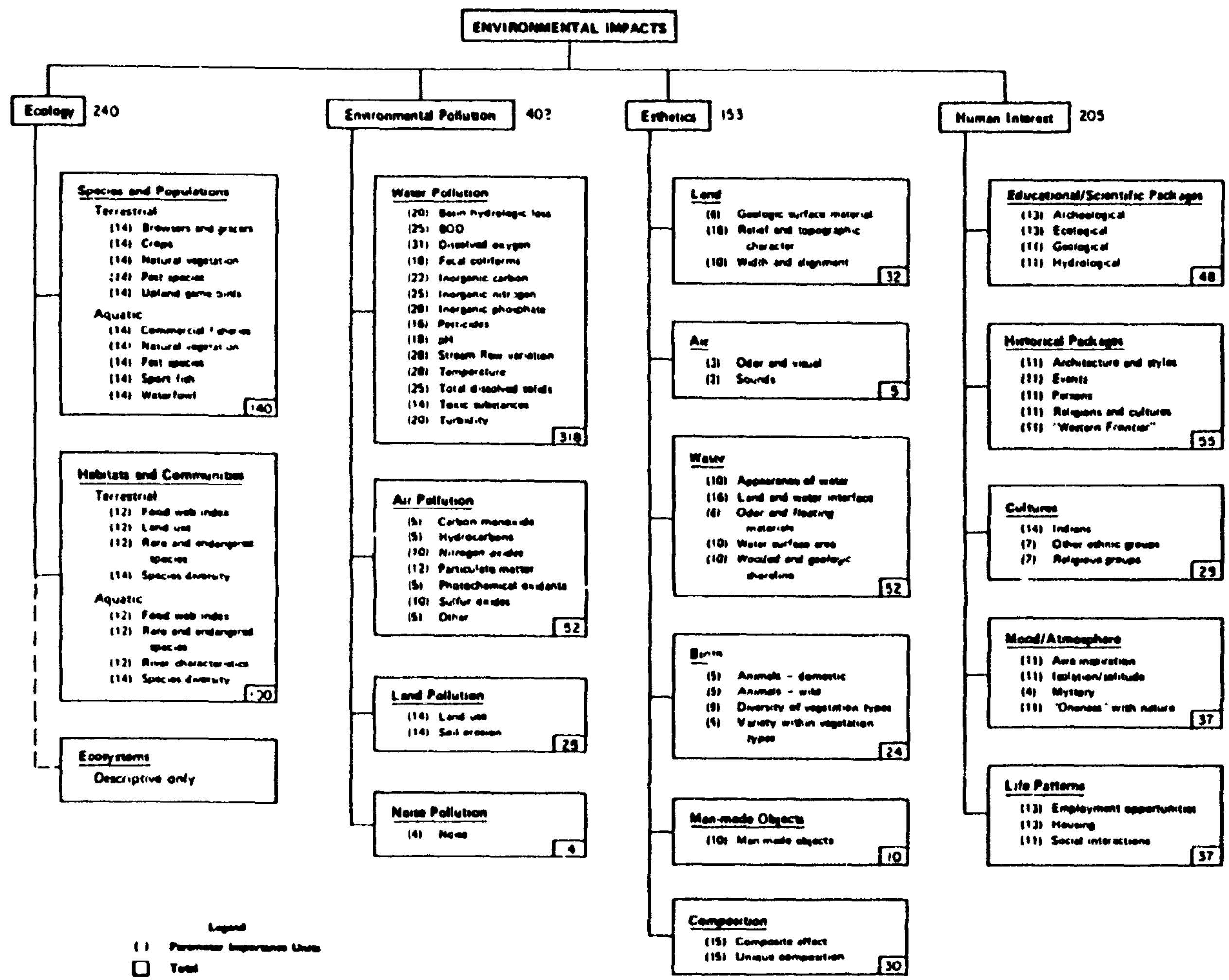


Fig. 2-3 Environmental Evaluation System, after Dee et. al., 1973

The EES provides a means for measuring or estimating selected environmental impacts of large-scale water resource development projects in commensurate units termed "environmental impact units" (EIU). A technique is necessary to transform all parameters into commensurate units. This technique consists of three steps.

STEP 1. Transforming parameter estimates "without" the project and then "with" the project into environmental quality. In the EES, environmental quality is defined as a value between 0 and 1, where 0 denotes extremely bad quality and 1 denotes very good quality. The transformation of a parameter estimate and environmental quality is achieved through the use of a value function relating the various levels of parameter estimates to the appropriate levels of environmental quality. The concept of a value function is given in Fig. 2-4. The parameter estimate used in the value function is a representative value obtained from environmental measurement data, level 4 of the EES.

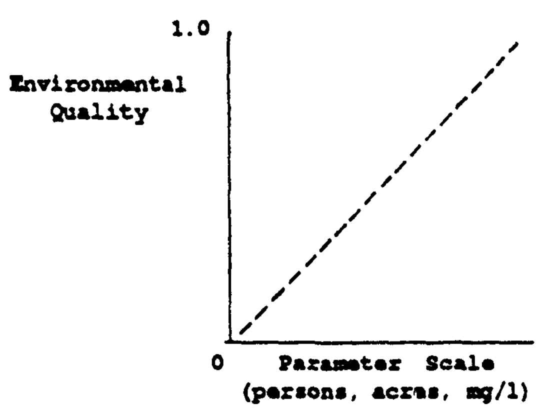


Fig. 2-4 Typical Value Function, after Dee et. al., 1973

STEP 2. Weighting of parameters. Since some parameters are more important than others, to reflect the relative importance of the EES parameters, a total of 1,000 points or parameter importance units (PIU) were distributed among the parameters. The number of PIU assigned to a parameter is an indicator of the degree to which water resource projects may disturb or enhance the dynamic stability of man's relationship with the natural and social environment. An assignment of the relative weights (PIU) was made by quantifying the research team's subjective value judgements. Sociopsychological scaling techniques and Delphi procedure were used to quantify the value judgements.

STEP 3. Obtaining commensurate units. In step 1 each set of parameter measurements was related to an environmental quality scale between 0 and 1, and in step 2 each parameter was assigned a relative importance. The results of both of these steps are combined in step 3 to obtain the desired commensurate units for environmental impact trade-offs. A difference in environmental impact units (EIU) between the expected future condition of environmental quality "without" the project and then "with" the project constitutes either an adverse (loss in EIU) or beneficial (gain in EIU) impact. Mathematically, this process may be represented as

$$E_I = \sum_{i=1}^{(i=m)} (V_i)_1 W_i - \sum_{i=1}^{(i=m)} (V_i)_2 W_i \tag{2-1}$$

where E_I is environmental impact; $(V_i)_1$ value in environmental quality of parameter i with a project; $(V_i)_2$ value in environmental quality of parameter i without a project; W_i the relative weight (importance) of parameter i; and m the total number of parameters.

The EES is useful as an aid in the determination of environmental impacts for water resource development projects. The system of parameters, value functions, and weights given in the EES constitutes a methodological foundation for environmental evaluations, although they should be improved as the system is used.

2.5 SUBSEQUENT STUDY

From the above literature review, it has become clear that large-scale water resource development projects could produce a sequence of beneficial and adverse changes within the river basin, and that every project generates its own particular effects on the environment. Based on previous studies of the Three Gorges Project, the subsequent study with the aid of the EES will make an attempt to investigate the environmental planning problems of the Three Gorges Dam, as below:

1. What are the major environmental effects in detail of the Three Gorges Project?
2. What is the difference between the two scores in EIU "with" and "without" the Three Gorges Project?
3. What is the difference between the two scores in EIU "with" the 150-m Storage Dam and "with" the 180-m Storage Dam?
4. What are the necessary considerations for minimizing adverse impacts resulting from impounding the Yangtze River by the Three Gorges Project?

CHAPTER III

MAJOR ENVIRONMENTAL IMPACTS OF THE PROJECT

Although the same basic physical process is at work in all large-scale water resource development projects, there are profound differences in their environmental effects. The Tennessee Valley Authority has been rightly regarded as a marvellous accomplishment (Baxter, 1977); "Egypt's Aswan High Dam is bringing prosperity to the country but with side effects so feared" (Abul-Atta, 1979). China's Three Gorges Project with its particular social, economic, and natural backgrounds, will undoubtedly produce environmental impacts different from any other large-scale water project. The major beneficial and adverse environmental impacts of this project will be analysed.

3.1 BENEFICIAL IMPACTS

The Three Gorges Dam is considered a large multi-purpose water resource project. It is conceived as a most suitable means (1) to prevent the densely populated areas of the Yangtze's middle and lower reaches from flooding; (2) to generate hydro-power required for promoting industrialization in Central-South and East China; and (3) to overcome treacherous shoals and obstinate shallows for modern watercraft navigation between Chongqing and Yichang. Irrigation is not among the project's purposes.

3.1.1 Flood Control

In the Yangtze Basin, distribution of precipitation is non-uniform throughout the year. Much of the annual precipitation is concentrated in summer when the warm, moist maritime monsoon dominates. Precipitation in the basin averages about 1000 mm annually, 544 mm of which (average runoff depth) comprises the source of the river water. In irregular climatic years, the rainfall in summer augments considerably and often causes disastrous floods. The longstanding need for such flood control makes the Three Gorges Project urgent.

A. Flood Hazards of The Yangtze

As mentioned previously, flood hazards are particularly pressing for the plains in the middle reach of the Yangtze, which have been repeatedly subjected to the river water overflowing the levees. Although the large levees have been built up to 16 metres above the adjacent alluvial plains, the maximum capacity of the Yangtze levees is 60,000 m^3s^{-1} around Shashi and Chenglingji, 70,000 and 80,000 around Wuhan and Hukou respectively. In fact, it has been indicated by flood investigation that 8 floods at Yichang exceeding 80,000 m^3s^{-1} capacity have occurred in history; 22 floods at Yichang with discharge rates of more than 60,000 m^3s^{-1} have been observed during the last century. Table 3-1 shows that the flood frequency is quite high in this extensive area.

In August 1931, disastrous flooding caused by an abundance of cyclonic depressions inundated virtually all of the plain. The town of Hankou (a part of Wuhan) for four months was covered with a layer of water 5-7 metres deep. The water of the overflowing river flooded a territory of 100,000 km^2, including 3.33×10^6 hectares of fields. Most unfortunately, about 185,000 persons lost their lives and 30×10^6 suffered from this flood.

Table 3-1. Highest Flood Peaks Statistics of the Yangtze

Period (year)	Discharge (cu. m/sec)	Site around Section of the Channel
10	60,000	Zhijiang
20	72,300	The Three Gorges
40	80,000	Yichang
100	87,000	Zhijiang
1000	110,000	Zhijiang

Source: EOPYR, 1986; Xu and Peng, 1986.

The 1954 flood was even larger. During this year in the region of Hankou, within the six summer months there were more than 1840 mm of precipitation and this was 550 mm above the index for 1931 summer precipitation. Although the amount of river overflow and the scale of destruction were incomparably less due chiefly to protective installations which had been put into operation in 1952, the hazards were tremendous. During July-August 1954, the maximum discharge of the river upstream of Changlingji was over 100,000 m^3s^{-1}, greatly exceeding the channel capacity of 60,000 m^3s^{-1}. Consequently, total flood water overflowing of the levees reached the amount of 102.3×10^9 m^3, equal to 22% of all discharges through Datong during these two months.

B. The Three Gorges Project for Flood Control

According to the long-term flood statistics, it is recognized that during the period (July-August) of high river-level the runoff generated in the Yangtze Basin above Yichang consists of 95% of flood discharge within the middle reach of the Yangtze, 60-80 and 55-76% of flood discharges at Chenglingji and Wuhan respectively (Xu & Peng, 1986). At this point, storing flood water within the channel above Yichang to a great extent means controlling flood hazards in the lower reach, and especially the middle reach of the Yangtze. Hopefully, the Three Gorges Dam will be located 40 km upstream of Yichang, just at the turning point of the river.

The maximum capacity of the Yangtze channel downstream of Yichang is far from meeting the need for disastrous-flood control. In particular, within the Jingjiang channel once the water volume exceeds the 10-year highest flood peak, the water quite likely overflows the levees. Most surprisingly, under current channel conditions, if heavy floods occur again as in 1954, 933,000 hectares of cultivated land will be destroyed and 7×10^6 persons will be displaced by emergency measures. If extremely disastrous floods emerge as those of 1860 or 1870 (105,000 m^3s^{-1} at Yichang), the area of farmland flooded will increase to 1.33×10^6 hectares, and 10×10^6 persons will suffer from the hazard, including 100,000 drowned (Xu & Peng, 1986). Fortunately, the Three Gorges Dam could fulfill the vital need of flood release for such large populations living in dangerous areas.

Provided that the project goes according to the 150-m Storage Scheme with a storage capacity of 22×10^9 m^3 for flood water, the highest flood of 20-100 years could be completely regulated by the dam alone, without the operation of Jingjiang hydro-technical installations; the highest flood of 100-1,000 years including the one in 1870 could be reduced down to 70,000-80,000 m^3s^{-1} at Zhijiang by the dam combined with the installations. Thus, protecting the Jingjiang levees from being broken will become possible. If the height of the dam is higher, the storage capacity of the reservoir for flood water increases correspondingly (Table 3-2).

Table 3-2. Beneficial Impacts of the Three Gorges Dam on Human Environment __ Flood Control

Typical Storage Scheme		150-m	160-m	170-m	180-m
Normal water-level behind the dam (m)		150	160	170	180
Height of the dam (m)		175	175	175	185
Water-level required before flood period (m)		130	145	150	160
Storage capacity for flood control below normal water level (billion cu m)		7.29	13.8	19.7	24.88
Total capacity for flood control (billion cu m)		22.0	22.0	19.7	24.88
Regulated flood at Zhijiang (cu. m/sec)	20-year flood	56,700	56,700	56,700	51,700
	1,000-year flood	71,700	71,700	75,700	76,100
20-year flood stored by dam (cu. m/sec)		15,600	15,600	15,600	20,600

Source: EOPYR, 1986; Xu and Peng 1986.

3.1.2 Hydro-electricity Generation

The Three Gorges Project will create enormous hydro-electric power generation. According to the 150-m Storage Scheme, the station's installed capacity will be 130×10^9 kilowatt-hours, almost 6 times that of the Aswan High Dam (2.1×10^6

kilowatt-hours). During an average year, its annual hydro-electric power production will amount to 66.7×10^9 kilowatt-hours, 3.6 times the total annual hydro-electric power production in the Tennessee Valley Authority in 1983 (18.5×10^6 kilowatt-hours). Most significantly, this huge amount of electric power could serve a large area; it can be transmitted to four Chinese economic coordination regions--North, East, Central-South and Southwest China--due to its favourable geographical location. It is full of promise to cope with the dilemma of persistent imbalance between power production and economic growth of East and Central-South China in the immediate future.

A. The Regional Energy Resources and Power Production

China's energy resources are sufficient to support a major industrialization program. Coal reserves and hydro-electric potential are very large, comparing favourably with those in the United States and the USSR; petroleum resources appear adequate to support substantial increases in future production. On the other hand, the distribution of energy resources in China is not favourable. The endowment and distribution leading resources poses fundamental problems for national power production: coal reserves are sufficient in the north territory but scarce in the south territory; hydraulic power is abundant in the west territory but poor in the east territory. Taken as a whole, the southeast territory, where two of the most-developed economic coordination regions are situated, is lacking almost completely both leading resources of coal and hydro-power.

Coal accounted for about 90% of all the primary energy available in China as of

1970 (Hsieh, 1973). Total reserves are estimated to range from 1.0 to 1.5×10^{12} tons; proven reserves probably range from 70 to 80×10^{9} tons, placing China third in the world after the United States and the USSR. Although deposits of various sizes are claimed to have been discovered in every province, most of the coal reserves are located north of the Yangtze River. In particular, two-thirds of the coal reserves are concentrated in Shanxi Province and the Nei Mongol Autonomous Region (Chen, 1986).

Table 3-3. World-Wide Situation of Hydro-Electric Power

Continents	Installed Capacity as Percentage of Potential Capacity (95% of Time)	Year
Africa	2.6%	1975
Asia	17.8%	1975
Europe (Including USSR)	61.0%	1975
North America	78.5%	1975
Latin America	14.1%	1975
Oceania	29.5%	1975
China	Below 4%	1986
	7%	1988

Sources: Saha, 1981; EOPYR, 1986; Lou, 1988.

The distribution of coal and hydro-electric resources is partly complementary. North and Northeast China are major coal producers, with large coal reserves and relatively limited water-power resources. In contrast, Southwest China lacks large coal reserves but apparently possesses immense hydro-electric resources, comprising 40% of all China's water-power resources (Chen, 1986). Many of the best potential hydro-electric sites are located in Yunnan, Western Sichuan, and Eastern Tibet--in sparsely populated areas distant from urban and industrial centres. Thermal electric power-plants, mostly coal fired, account for over 70% of the installed generation capacity of the country; hydro-electric plants make up the rest (Hsieh, 1973). Despite the enormous potential of 370×10^6 kilowatt-hours water-power available (Lou, 1988), the development of hydro-electric power continues to be slow in China, compared with the rest of the world (Table, 3-3).

Most of China's electric power facilities are concentrated in the industrialized Northeast, in the Beijing area, and in the Shanghai-Nanjing region. The principal power-plants as well as the three major transmission networks serve these areas. Separate power systems, comprising a number of small centres with rudimentary interconnections, serve the main industrial and urban centres in the densely populated middle-Yangtze valley, Sichuan Basin, and scattered areas of south China extending from Zhejiang on the coast to Yunnan in the Southwest. In relation to economic growth in the next decades, China's electric industry exists under high pressure, facing the challenge of electricity shortages.

B. Increase in the Demand for Electricity

In fact, the electric power industry of East and Central-South China hardly meets present demands. Due to insufficient power supply factories in Wuhan sometimes have to stop production; East China's electric transmission network operates under unusual conditions. According to popular standards of operation, the normal daily load rate and the maximum annual load hours are not permitted to exceed 8.5 and 6500 hours respectively. Actually, these two parameters of East China's network are 9.0 and 7300 (Chen, 1986). Apparently, the fear is that if no immediate, effective measures are taken, the insufficient power supply could result in disaster for modern Chinese industrial society.

The concentration of China's industry remains in the eastern part of the territory. East China has about one-third of the country's population as well as industrial and agricultural production. It leads in the manufacture of textiles and many other consumer goods, is second in total industrial production, and ranks high in the production of chemicals, electric power, and machinery. Much of the region's productive capacity is located in Shanghai, China's largest industrial and commercial metropolis. Central-South China, ranking second after the East in population, is China's largest producer of tractors and sugar. Heavy industry is concentrated in the middle Yangtze Valley at Wuhan and at Loyang in northern Honan. The region is an important producer of raw materials, particularly nonferrous metals. North China ranks third in total industrial production. The region is a major producer of steam locomotives, tractors, iron and steel, chemicals, electric power, textiles, and paper. Southwest China is the predominantly mountainous and formerly isolated region. Using the limited industrial base started during the World War II, new heavy industrial facilities specializing in electronic equipment and chemicals have been constructed in the Sichuan Basin, where growing industrial areas are centred at Chongqing and Chengdu. All these four of China's six economic coordination regions within the area accessible to the power from the project could be favoured by the Three Gorges Dam.

It has been learned from experience that long-term economic growth requires an increase in power production at the proportional rate. Based on China's 1980-2000 national economic plan, Chen (1986) estimated that the national annual electric power production should achieve 500×10^9 kilowatt-hours by 1990, a yearly increase of 5.2%, $1{,}200\times10^9$ kilowatt-hours by 2000 and $1{,}846\times10^9$ kilowatt-hours by 2005, a yearly increase of 9.1%. Accordingly, Chen (1986) predicted the imbalance in the future power demand-supply budget of the four regions concerned (Table 3-4).

Table 3-4. Power Supply-Demand Budget of the Four Regions: 1980-2000

Region	East	Central-South	North	South-West
Increase required in installed capacity (million kh)	36	30	29	15
Increase required in electricity supply (billion kh)	200	187	150	86.5
Increase available in installed capacity of hydro-power (million kh)	3.5	14.6	very little	10
Increase available in hydro-power (billion kh)	15	78.2	very little	50
Increase available in installed capacity except of hydro-power (million kh)	13.5	very limited	35	5
Increase available in electricity supply except of hydro-power (billion kh)	85	very limited	200	36.5
Imbalance in electricity supply budget (billion kh)	-100	----	+50	0

Source: Chen, 1986.

The conclusion from Table 3-4 is that electric power production could not keep pace with economic growth in East and Central-South China in upcoming years. In turn, economic growth can not be realized at the rate planned. From this point of view, the Three Gorges Project is of unusual importance to the future development of these two regions.

C. The Three Gorges Project for Power Production

With the endowment of a plentiful, steady inflow and a narrow, deep channel, the Three Gorges is an excellent place for building an immense hydro-power generation project. There is very little fear about geophysical issues because a long-term study has demonstrated that granite underlies the reservoir area and the Three Gorges region is by no means active in seismicity. It is situated in the central part of China, close to Central-South China and not far away from East China, both of which lack energy resources but need much more electricity immediately.

Table 3-5. Comparison of the Three Gorges Dam and the Five Proposed Dams: Cost and Gain

Cost and Gain		The Three Gorges Dam	Five Proposed Generations
Earth-stone required (cu. m/1000 kh)	Installed capacity	8.6	13.7
	Power production	16.5	38.1
Concrete required (cu. m/1000 kh)	Installed capacity	2.42	1.75
	Power production	0.24	0.38
Investment (Yuan/1000 kh)	Installed capacity	1220	1370
	Power production	0.24	0.38
Flooding land (ha/million kh)	Installed capacity	112	217
	Power production	144.1	403.5
Displaced People (person/ million kh)	Installed capacity	45.4	44.0
	Power production	4.48	12.24

Source: Chen, 1986.

In terms of power station investment, the Three Gorges Dam is economical and feasible compared with others (Table 3-5). Among many, five middle-scale hydro-electric generation plans (Pengshui, Geheyan, Wuqiangxi, Tankeng and Shanxi) have been studied in detail and will have been completed by the year 2000. On the average, the per-kilowatt-hour installed capacity of these five proposed power projects will require building materials of earth-stone and concrete, land flooded, and population displaced more than 50, 38, 73 and 94% respectively of those of the Three Gorges Project. In per kilowatt-hour installed capacity construction cost, the five projects are much more expensive too.

In general, hydro-power has some advantages over electricity generation from other sources. First, water is a renewable resource. Rivers run year after year, replenished by the hydrological cycle within some natural variation. One unit of water generates electricity cumulatively by passing through the turbines of many dams along the descent of a river. A second advantage of water for hydro-power is that it produces "clean" electricity. Finally, a hydro-power facility requires little maintenance, has infrequent shutdowns, and operates with a large degree of flexibility; in other words, it can respond quickly to peak load demands.

One kilowatt-hour of electricity is equal to ten hours of human effort. Or for each kilowatt-hour electricity produced, ten hours of labour are saved. As Lilienthal, one of the first directors of the Tennessee Valley Authority pointed out (Street, 1981):

> "The quantity of electrical energy in the hands of the people is a modern measure of the people's command over their resources and the best single measure for industrialization, their potentialities for the future."

In fact, selling electricity cheaply and providing power lines to rural areas certainly speeded the economic and social development of the Tennessee Valley Region (Street, 1981). In 1976, Egypt completed an impressive rural electrification program that became feasible only after the construction of the Aswan High Dam (Fahim, 1981, p. 15). Significantly, it has been proven both by the Tennessee Valley Authority and the Aswan High Dam that the formation of dams not only causes displacement of people but also creates employment opportunities for thousands of workers.

Table 3-6. Beneficial Impacts of the Three Gorges Dam on Human Environment __ Power Production

Typical Storage Scheme		150-m	160-m	170-m	180-m
Installed capacity (million kh)		13.0	14.82	16.9	18.72
Annual electric production (billion kh)	Minimum	33.2	38.1	46.0	53.7
	Average	66.7	73.2	78.5	89.1

Source: EOPYR, 1986.

The total annual electricity generation including hydro, coal and nuclear power in the Tennessee Valley Region was estimated at about 90×10^9 kilowatt-hours in 1980 (Street, 1981). If the Three Gorges Project is carried out according to the 180-m Storage Scheme, the annual hydro-power supply by the dam will amount to 89.1×10^9 kilowatt-hours, very close to the total annual power production of the whole Tennessee Valley Region. Even if the 150-m Storage Scheme is put into practice, the annual power production of the Three Gorges Dam will still be immense, more than 8 times the maximum annual electric power production (8×10^9 kilowatt-hours) of the Aswan High Dam. Without doubt, China's Three Gorges Dam, serving as a power source

(Table 3-6), will become a vital economic milestone in national development plans.

3.1.3 Waterway Improvement

China has an extensive network of rivers and tributaries which remain a significant element of the country's entire transportation system. Of these inland waterways, 100,000 km are navigable by small craft and 30,000 km by steamboats. The most important artery of this network is the longest of China's rivers, the Yangtze. It is navigable for 2,900 km from the mouth at Shanghai to Yibin year-round due to its plentiful as well as ice-free flow. Within the Yangtze Basin, 70,000-km of waterways are joined in China's transportation system by railroads and trucks, constituting the largest comprehensive traffic network of the country. In 1983, foreign and domestic commerce totaled 60×10^9 ton-km on the Yangtze and its tributaries, 85% of the amount of China's total inland waterway traffic.

A. The Yangtze's Present Channel

The Yangtze can be divided into five sections on the basis of navigability. The first section extends 183 km above Yibin. The character of the typical mountain river makes navigation difficult here, allowing navigation only for 80-200 ton barges. The second reach of the river stretches from Yibin to Chongqing in Sichuan Basin, a distance of 385 km. A section extending 81 km upstream of Chongqing is navigable for 800-ton barges; the rest for barges below 300-ton. Between Chongqing and Yichang lies the third section, 660 km long. Under natural conditions, the currents here are swift and the riverbeds are marked by the unevenness of the drop and the significant rapids in the long profile. At most, 1500-ton barges can navigate this section but they often run some traffic risks. Particularly within the Three Gorges, "perils of the sea" take place frequently. The fourth section, 626 km long between Yichang and Wuhan, can be used by vessels of 2,000-3,000 tons during the season of high water level, and by boats of 1,000-2,000 tons when shallows and shoals appear during the period of low water level. The last section of the river, 1,125 km long from Wuhan to Shanghai, has a wide channel and a high volume of flow, and year-round navigation of 5,000 ton barges becomes possible; yet there exist about 30 shallows during the period of the low water level.

The Yangtze flows eastward, connecting a number of large industry centres. Unfortunately, navigation for large vessels becomes increasingly more limited in a westward direction. Especially between Chongqing and Yichang, the use of the river for transport is badly impeded. In detail, within the 660-km long channel, 139 dangerous sites spread below the water surface (Table 3-7).

Table 3-7. Dangerous Sites in the Yangtze Channel between Chongqing and Yichang

Dangerous Site	During the Period of Water Levels			Total Amount
	High Level	Middle Level	Low Level	
Rapid	37	24	16	77
Shoal	5	19	15	39
Shallow	0	0	23	23
Total amount	42	43	54	139

Source: Yao, L. Q., 1986.

To the shipper, waterway provides certain advantages and disadvantages over the alternative modes of transportation. The most obvious drawback is the slow pace of barge transportation, resulting from circuitous and indirect routes, waiting time at congested locks, and delays caused by weather conditions. However, barge transportation is almost always the cheapest form of commodity transport, and for industry located at the riverside it is often the most convenient. When time is not of the essence, barge transportation is an economical choice.

Trucks, being very expensive, however quick and convenient, are not in direct competition with barge traffic, but railroads are. Prices on many routes are fiercely competitive, as the railroads can lower their rates on lines where there are waterway alternatives while maintaining higher rates elsewhere. It is not uncommon to find evidence of seasonal price discrimination on the part of the railroads. For instance, winter railroad rates may change on northern routes in the United States, depending on whether or not competing waterways are open for passage (Gibbons, 1976). By contrast, the price on the waterway between Chongqing and Yichang is strongly competitive, because the railroad system works in circuitous and indirect routes and weather conditions produce very little effect on the waterway traffic.

Regrettably, recent waterborne commerce on the Yangtze transported from Sichuan downstream annually has been about 5×10^6 tons, heavily restricted by the channel situations. Bulk commodities including food, coal, lumber, cement, textiles and nonferrous metal remain in increasing demand for much transportation. It is predicted that commodities required to be carried out of Sichuan by the Yangtze channel will amount to 23×10^6 tons by the year 2000, 50×10^6 tons by 2030 (Yao, L. Q., 1986). This requirement makes a complete improvement of the channel urgent.

The only hope is that the reservoir in the Three Gorges could inundate all dangerous sites below the present water surface, resulting in the disappearance of the rapids, shoals and shallows, reduction of the flow speed, and regulation of the water level fluctuation. Of course, an increase in waterborne transportation as well as navigation safety will come immediately after the completion of the dam. Among the four alternative storage schemes, the 180-m Scheme is the best one for improving the waterway conditions between Chongqing and Yichang (Table 3-8).

Table 3-8. Beneficial Impacts of the Three Gorges Dam on Economic Environment __ Waterway Improvement

Typical Storage Scheme	150-m	160-m	170-m	180-m
Reservoir waterway created (km)	450-550	530-600	550-650	600-700
Maximum dangerous sites inundated	88	94	99	100
Dangerous sites inundated as a percentage of all	88	94	99	100

Source: EOPYR, 1986; Yao, L. Q., 1986.

3.2 ADVERSE IMPACTS

The Three Gorges Project will achieve these goals if everything goes as planned, thus providing a few of China's economic regions with potential for further social and economic development. Nevertheless, few dams are built without conflict; the Three Gorges Dam is no exception. It will create a variety of adverse impacts on the human, biological, and physical environments downstream and upstream. Perhaps no other dam has had such dramatic effects.

3.2.1 Land Inundation and Population Displacement

According to the 150-m Storage Scheme, the Three Gorges reservoir will occupy a position from 107° 20'-111° 01' in longitude and 30° 30'-31° 20' in latitude, much of which lies in Sichuan; some in Hubei. It will cover 670 km^2, of which 340 km^2 is the original river water area, and 330 km^2 is land inundated by the added reservoir. It will be 500 km long, and 1.34 km wide on the average, being a typical river channel reservoir. Its shape will be different from that of other lakes. The shoreline development (the ratio of the length of the shoreline to the circumference of a circle of the same area as the lake) is much higher than for natural lakes as well as many other man-made lakes.

Compared with the Volta Lake (in Ghana) and the Aswan Lake, the Three Gorges Lake will flood a relatively small area of land surface. The Volta Lake occupies 8,482 km^2, or 3.6% of the surface area of the country; the Aswan Lake has a surface area of 6,276 km^2. On the other hand, the population displaced by the Three Gorges Lake is not comparable to that displaced by the Volta and Aswan Aswan Lakes: 80,000 and 100,000 persons were relocated from the Volta Lake and the Aswan Lake regions respectively, but, based on June 1986 statistics, the Three Gorges Lake will cause 330,397 people to be displaced from 14 counties and cities extending along the Yangtze's banks. Also, this population is characterized by a majority of urban residents rather than rural inhabitants as in most cases.

The Three Gorges Reservoir area is highly urbanized and densely populated. In some urban areas, building densities (the ratio of the area occupied by buildings to all land surface area of the region) reach as high as 64%; population densities here average about 20,000 persons per km^2. The average population density in the reservoir-flooded area is about 1,000 persons per km^2. Urban residents constitute 50.1% of the total population to be displaced; rural inhabitants make up the rest. Ten towns and cities affected by the inundation have 350,000 residents, of whom 144,000 persons must be moved; 4 towns of the 10 will be flooded completely and the rest will be affected partly. The largest city to be inundated is Wanxian with a population of 128,000; the smallest one with 9,000 residents. Rural inhabitants of 183,000 asked to be relocated are distributed over an area of 14 counties and cities. Of the displaced rural population about 5,000 each are distributed in 7 counties and cities; 5,000-10,000 in 2 counties; 10,000-20,000 in 2 counties; more than 20,000 in the 3 remaining counties (Yao, B. H., 1986).

The population relocation in connection with the Three Gorges Project, both from the point of view of the local people and from that of the government, is the most difficult process associated with the creation of such a man-made lake. Relocation is compulsory, so the local people have no option but to move or be moved. Perhaps certain individuals may welcome resettlement, but the majority resent being forced to move. Farmers especially never want to leave their favorite, productive land for an unfamiliar environment. Even if farmers are moved, they not only need greater assistance but will also wish to be relocated as a community. This resentment in itself is apt to foster anti-government attitudes, which make planned development more complicated. Since the people do not ask to be displaced, they expect the government to take over the major responsibility for their rehabilitation. If the government does "too little", it may be severely criticized; if it does "too much", a dependence relationship can develop, as it has happened in other projects. Indeed, the population displacement has been regarded as one of the major barriers in starting the dam.

While the benefits from the project are directly proportional to the height of the normal water level behind the dam, the hazard of the population displacement also increases when the dam grows up. If the water level rises 10 metres higher, the number of displaced people could increase massively (Table 3-9). It is because of problems associated with the population displacement that China prefers the 150-m Storage Scheme to other higher ones.

Table 3-9. Adverse Impacts of the Three Gorges Dam on Human Environment __ Population Displacement

Typical Storage Scheme	150-m	160-m	170-m	180-m
Cultivated land flooded (1,000 ha)	9.74	14.62	19.02	26.41
Population displaced	330,000	422,000	622,000	768,000

Source: EOPYR, 1986.

3.2.2 Destruction of Fish Habitat

The modification of downstream river-flow characteristics due to impoundment can have a variety of effects upon fish species: food production, stimuli for migration, the success of migration and spawning, the survival of eggs and juveniles, spatial requirements, and species composition, can all be adversely affected (Fraser, 1972). The Three Gorges Dam, firstly, will provide a barrier to fish movement. Some fish species will disappear in the Yangtze upstream of the dam. Also, if the higher alternative storage scheme is constructed, the alteration of water-temperature of the river could result, thus causing reduction in the reproductive ability of native fishes which require specific minimum temperature as triggering mechanisms for spawning, or for the subsequent survival of eggs and young.

A. Interruption of Fish Migration

Many important "commercial" fishes are diadromous, that is, they migrate between the river and the sea, either for breeding or for feeding. Anadromous species, such as Acipenseridae (Sturgeon) and salmonids, which breed in fresh water, have been particularly affected by impoundments. Some native fish species may be found in a reservoir for a few years after dam closure, but if the suitable spawning grounds are inaccessible, extinction will result because of a lack of recruitment (Petts, 1984, p. 225).

For the four predominant fish species, the black carp, the grass carp, the sliver carp, and the variegated carp, which are non-migratory, the Three Gorges Dam will hardly destroy or deprive their previous spawning areas and will not create any obstruction to their spawning. Investigation shows that the distribution of spawning-grounds and the reproductive ability of these four species almost remain the same after the closure of the Gezhou Dam 40 km downstream of the site of the Three Gorges Dam a few years ago (Hu, 1986). However, the Gezhou Dam has presented to some of diadromous fish in the Yangtze a barrier to upstream and downstream migration.

There are 7 species of migratory fishes in the Yangtze and its tributaries. Only one of them, Manli, breeds in the sea and grows in the fresh water of the river. A number of these species can migrate a long distance above the Three Gorges. The rest, except for Chinese Sturgeon, have their spawning-grounds and migratory spaces downstream of Yichang. Chinese Sturgeon breeds in the section of the Yangtze both downstream and upstream of the Three Gorges. Therefore, the Three Gorges Dam could not result in extinction of the migratory species but present problems to Chinese Sturgeon and Manli moving to parts of their previous spawning-grounds, so these two species could disappear above the dam if no measure for their migration through the barrier is taken. So far it seems that the "barrier effect" imposed by the Three Gorges Dam on the migratory fish species could not constitute one of the major adverse environmental impacts of the project.

B. Cold-Water Release

Water flowing into a reservoir is frequently different from that already present in temperature, or in content of dissolved or suspended solids, or in some combination of these, and consequently in density (Petts, 1986, p. 68). The inflow of water of different density to that already stored in the reservoir will result in the formation of density currents within the lake. The inflow seeks its density level, moves along this level, and generates compensating currents. As a result, unusual and complex patterns of quality stratification may occur if this property of the inflowing water is different from that of the water already present. Because of the density currents, the inflowing water can not immediately mix with the water of the reservoir. Thus, a stratification pattern in the reservoir could be established.

The annual pattern of density currents may have a marked seasonality. The inflow water is often colder in winter and warmer in summer, than that of the reservoir. During winter a reservoir may experience complete vertical mixing, and the inflow passes through the reservoir as an underflow, which is relatively cold to the water already stored in the reservoir but relatively warm to that currently flowing into the reservoir. On the contrary, during summer, as the inflow has a temperature higher than that of the reservoir, it forms an overflow spreading out as surface water. Often when cold water from the reservoir is released downstream, it does damage to fish species with specific temperature requirements.

However, it has been suggested that not every reservoir exists in stratification patterns. Water stratification occurs only if the water in the reservoir moves slowly and has a long retention-time; otherwise turbidity currents could dominate the characteristics of the reservoir, ensuring the release-water similar to the inflow at the same time. Simply, this interrelation could be determined by the following model (Hu, 1986):

$$A = \frac{Q}{C} \qquad (3\text{-}1)$$

Where A is the coefficient of reservoir water circulation; Q the amount of water flowing into a reservoir annually; and C reservoir storage capacity.

Table 3-10. Adverse Impacts of the Three Gorges Dam on Biological Environment __ Destruction of Fish Habitat

Typical Storage Scheme	150-m	160-m	170-m	180-m
Reservoir storage capacity (billion cu m)	19.69	26.20	34.40	45.57
Coefficient of reservoir water circulation	22.85	17.18	13.08	9.87

If $A < 10$, water stratification occurs; if $A > 20$, water turbidity occurs. Based on this model, coefficients for the four storage schemes for the Three Gorges Project are obtained as shown in Table 3-10. Only the 150-m's coefficient is less than 20, not resulting in water stratification and cold-water release of the reservoir.

In many cases, water temperature may provide the dominant limiting condition. For example, cold-water release from the high dams of Colorado River have resulted in the decline in native fish abundance (Holden and Stalnaker, 1975). Cold discharges from Glen Canyon Dam, together with little solar warming because of high canyon walls and the absence of large, warm-water tributaries, have made the river unfavourable for most native fish. The native *Catostomus latipinnis* and *C. discobulus* were the dominant species, but, after dam completion, introduced species came to outnumber the native species by 19 to 10, and four endemics--*Ptychocheilus lucius*, *Gila elegans*, *G. cypha*, and *Xyrauchen texanus*--were considered to be endangered. Indeed, the Colorado River in the Grand Canyon remains too cold for most native fish for over 400 km below Glen Canyon Dam. Prior to the filling of Flaming Gorges Reservoir, the estimated maximum net gain in weight of Rainbow Trout (*Salmo gairdneri*), of $10.4\times10^3 kg\ km^{-2}$, was associated with temperatures of 20-36° C, but after filling this dropped to $0.2\times10^3 kg\ km^{-2}$ at the reduced water temperature-range of 22-31° C (Mullan et. al., 1976).

Despite the relative abundance of insect food below Flaming Gorge Reservoir, *S. gairdneri* were concentrated not in areas of high velocity, associated with the typical aggressive drift-feeding, but in the areas of least velocity, where Algae were most abundant. This suggests that the fish were forced by low temperatures, resulting in low metabolism, to seek sheltered positions out of the main currents and away from their major food-source (Mullan et. al., 1976). Similarly, in Tennessee, apparently good spawning habitat for *Polyodon sp.* exists within the Caney Fork River below Center Hill Dam, but no eggs or larvae were observed, despite the movement of large fish into the channel over a prolonged period: the temperature of the reservoir releases were 1-1.5° C colder during the spawning period than the lowest temperature at which *Polyodon larvae* have been collected (Pasch et. al., 1980).

Additionally, a deep, large reservoir will often dominate the characteristics of other reservoirs and outflows downstream. Dendy and Stroud (1949) cite several examples where a chain of reservoirs are dominated by one, large, deep-release dam. The Little Tennessee River, for example, is regulated by three line-of-the-river impoundments. Prior to the construction of the relatively young Fontana Reservoir upstream, water temperature in summer below the two combined, low-capacity reservoirs were usually about 25° C, but after completion of Fontana Dam the water temperature fell to about 14° C. The data indicated that water release from Fontana Dam passes through the lower two reservoirs in less than 14 days, so that the changes in the character of water leaving Fontana are felt quickly in the reservoir storage downstream, and the influence of such change was transmitted to the river below the dams.

From the above-examples, we conclude that if any one of the three higher storage schemes for the Three Gorges Project is implemented, the decline in the native fish abundance will appear. Apparently this is due to the water temperature change. Also, cold discharges leaving the Three Gorges Reservoir could make Gezhou Reservoir far more unfavourable for some native fish.

3.2.3 Reservoir Siltation and Coastal Degradation

When once completed, reservoirs provide areas of relatively low current velocity, which allow the materials that are held in suspension to settle out, so that the storage capacity of the reservoir will be reduced year after year. Meanwhile, major flow regulation reservoirs can modify the natural seasonal discharge of rivers, resulting in dramatic alternation of the water circulation pattern as well as in significant consequences to the ecology of the adjacent marine environment in the estuarine and nearshore zone.

A. Reservoir Sedimentation

Silting belongs to the most dangerous phenomena taking place in reservoirs. It often affects both the operational plan of existing reservoirs (by causing depletion of their storage space) and t › economic analysis of planned investments based on reservoir use. Nevertheless, as soon as a dam is operational, sediment to be trapped will begin within its storage volume. For instance, the Heisongho reservoir on the Yellow River in China having the highest sediment load in the world (1.6×10^9 tons per year), lost nearly 20% of its storage capacity within 3 years of completion. Even after operations to reduce the sediment rate, the expected life of the reservoir is less than 80 years (Walling, 1981). Another multi-purpose reservoir in the same catchment has a more adverse fate: the Sanmenxia lost 62% of its capacity in the first four years. With these two extreme examples in mind, at the planning stage of the Three Gorges Project the fear is that the reservoir will quickly exhaust to such an extent that the full demand for power production and flood control may not be met.

The rate of a reservoir siltation is largely dependent on its trap efficiency--the percentage of incoming sediment deposited within the reservoir. The use of a C/I (Capacity/Inflow) ratio for determining reservoir storage requirements was introduced by Hazan (1914), and was adopted as an index of sediment-trap efficiency by Brune (1953), having been well developed for estimating the loss of a reservoir's capacity in a given time period or its total useful life by Gill (1979).

In general, a low C/I ratio suggests rapid sedimentation rate, and the high ratio describes reservoirs having low rates of filling. Reservoirs of very low C/I ratio may have a trap efficiency of zero or less during some periods of streamflow conditions. In contrast, reservoirs of very high C/I ratio often experience continuous sedimentation, giving rise to clear-water releases downstream.

Table 3-11. Correlation of Trap Efficiency with C/I, after Gill, 1979

Curve Description	$f(C/I)$
Coarse	$\frac{(C/I)^2}{0.00003+0.006297(C/I)+0.994701(C/I)^2}$
Median	$\frac{(C/I)}{0.012+1.02(C/I)}$
Fine	$\frac{(C/I)^3}{0.000001-0.000133(C/I)+0.02621(C/I)^2+1.02655(C/I)^3}$

The equations in Table 3-11 having a very close fit to the three trap efficiency curves proposed by Brune (1953) were presented by Gill (1979) as correlation of trap efficiency (E) with C/I, and commonly used in estimating the useful life of reservoirs. Using these equations, the estimated trap efficiencies of the Three Gorges Reservoirs at the beginning of the operation are given in Table 3-12.

Table 3-12. Estimated Trap Efficiencies of the Three Gorges Reservoirs

Typical Storage Scheme		150-m	160-m	170-m	180-m
Capacity (billion cu m)		19.69	26.20	34.40	44.57
Initial trap efficiency (%)	Coarse	87.7	90.6	92.8	94.5
	Median	77.2	81.5	84.9	87.6
	Fine	63.7	69.3	74.1	78.2
Half-capacity trap efficiency (%)	Coarse	77.6	82.3	86.1	89.0
	Median	63.7	69.8	74.9	79.2
	Fine	48.9	55.2	61.0	66.2

The time rate at which reservoir capacity lost by sedimentation is expressed by Gill (1988) as

$$\frac{dc}{dt} = -\frac{GE}{\gamma} \tag{3-2}$$

Where C is reservoir capacity; t time in years; G the annual rate of inflow of sediment transport; E trap efficiency; and γ the specific weight of deposited sediments, which varies with the passage of time due to the sediment consolidation with time.

E can be expressed algebraically as a function of C/I (Table 3-11):

$$E = f\left(\frac{C}{I}\right) \tag{3-3}$$

The solution of Eq. (3-2) using Eq. (3-3) can be written as:

$$\phi(\frac{C}{I}) = \frac{G}{I}\int\frac{dt}{\gamma} \tag{3-4}$$

The functions $\phi(C/I)$ for the three efficiency curves, produced by Gill (1979) by combining Eq. (3-2) with the three equations in Table 3-11, are given in Table 3-13. For the effect of consideration on the specific weight of the sediments, Lane and Koelzer (1953) proposed the following empirical relationship:

$$\gamma = \gamma_1 + B\log(t) \tag{3-5}$$

Where γ_1 is the specific weight of the deposited sediment at the end of the first year of reservoir filling, and B is a constant having different values for different types of sediments and different types of submergence conditions in the reservoir. Values of γ_1 and B as proposed by Lane and Koelzer (1953) are given in Table 3-14.

Table 3-13. The Functions $\phi(C/I)$ for the Three Efficiency Curves, after Gill, 1979

Curve Description	$\phi(C/I)$
Coarse	$0.994701[Co-C]/I+0.006297Ln[Co/I]-0.000003[I/Co-I/C]$
Median	$0.012Ln[Co/C]+1.02[Co-C]/I$
Fine	$1.02655[Co-C]/I+0.02621Ln[Co/C]+0.000133[I/Co-I/C]$ $-0.00000051[I^2/Co^2-I^2/C^2]$
Co: Initial capacity of the reservoir.	

Table 3-14. Constants for Estimating the Specific Weight of Sediment Deposits after One Year, after Lane and Koelzer, 1953

Reservoir Operation	Sand		Silt		Clay	
	γ_1	B	γ_1	B	γ_1	B
	(lb/cu. ft)					
Sediment always submerged or nearly submerged	93	0	65	5.7	30	16.0
Normally a moderate reservoir drawdown	93	0	74	2.7	46	10.7
Normally considerable reservoir drawdown	93	0	79	1.0	60	6.0
Reservoir normally empty	93	0	82	0	78	0

To convert lb/cu. ft into kg/cu. ft multiply by 16.1.

For convenience of solving Eq. (3-4), Eq. (3-5) can be replaced reasonably by the following equation:

$$\gamma = \gamma_1 t^n \tag{3-6}$$

Where

$$n = 0.5 log\,(1+\frac{2B}{\gamma_1}) \tag{3-7}$$

Specific weights obtained by Eq. (3-5) and Eq. (3-6) at different values of t are compared with each other for silt and clay for the "permanently submerged condition", and the agreement is reasonably close and acceptable, considering that Eq. (3-6) is an empirical relationship (Gill, 1988). Using Eq. (3-6) in Eq. (3-4) gives:

$$\phi(\frac{C}{I}) = \frac{G}{I}\int\frac{dt}{\gamma_1 t^n} \tag{3-8}$$

Which is solved to give:

$$\phi(\frac{C}{I}) = \frac{Gt^{(1-n)}}{I\gamma_1(1-n)} = \frac{Gt}{I\gamma(1-n)} \qquad (3\text{-}9)$$

Using Eq. (3-9) and the equations in Table 3-13, the loss of reservoir capacity in a given year after the reservoir filling can be obtained. Based on this computational procedure, the useful life of the Three Gorges Reservoir will be treated next.

Table 3-15. A Programme for Planning the Useful Life of a Reservoir

PROGRAMME

```
      REAL I, N
      READ*,SAP,SAW,SIP,SIW,CP,CW,SAY1,SIY1,CY1,I,G,C0,X,T
      W=SAP*SAW+SIP*SIW+CP*CW
      Y1=SAP*SAY1+SIP*SIY1+CP*CY1
1     Y=Y1+W*LOG10(T)
      N=0.5*LOG10(1.+(2.*W)/Y1)
      A=1.02655*(C0-X)/I
      B=0.02621*LOG(C0/X)
      C=0.000133*I*((1./C0)-(1./X))
      D=0.00000051*I**2.*((1./C0**2.)-(1./X**2.))
      P=(A+B+C-D)*Y*I/G
      IF (ABS(P-T).LT.0.001) GO TO 2
      T=P
      GO TO 1
2     WRITE*, P
      END
```

SAP: Percentage of sand in the grain size distribution;
SAW: A constant for estimating the specific weight of sand;
SIP: Percentage of silt in the grain size distribution;
SIW: A constant for estimating the specific weight of silt;
CP: Percentage of clay in the grain size distribution;
CW: A constant for estimating the specific weight of clay;
SAY1: Specific weight of sand deposited after one year;
SIY1: Specific weight of silt deposited after one year;
CY1: Specific weight of clay deposited after one year;
I: Mean annual runoff;
G: Annual rate of sediment transport;
C0: Initial capacity of the reservoir;
X: Reservoir capacity;
T: Assumed years for which the reservoir loses its capacity of (C0-X);
P: Years for which the reservoir loses its capacity of (C0-X).

The four selected reservoirs of the Three Gorges Project have their initial capacities of 19.69, 26.2, 34.4, and $44.57\times10^9\ m^3$ respectively. The annual inflow of the reservoirs averages $451\times10^9\ m^3$, and the annual rate of sediment transport is 523×10^6 tons (Chen, Z. M., 1986). Assuming a moderate reservoir drawdown, the trap efficiency curve for fine sediments and the grain size distribution of 100% silt, the time in which the reservoirs will lose percentages of their initial capacities by sedimentation can be determined by running the Fortran 77 programme in Table 3-15 written by the author basically after Gill's computational procedure (1988). The periods in which half of each Three Gorges Reservoir will be filled are given in Table 3-16.

Table 3-16. Half-Filled Years of the Three Gorges Reservoirs

Typical Storage Scheme	150-m	160-m	170-m	180-m
Initial capacity (billion cu m)	19.69	26.20	34.40	44.57
Half-filled years	42.7	51.4	62.3	75.6
Mean rate of volume loss (million cu. m/year)	230.56	254.86	276.08	294.77
Annual volume loss as a percentage of initial storage capacity	1.17	0.97	0.80	0.66

Obviously, both the rates of capacity loss per year and annual capacity loss as a percentage of initial capacity, compared with these of Sanmenxia and Heisongho Reservoirs, are quite low due to the very small ratio (C/I) of each Three Gorges Reservoir. Additionally, the Three Gorges Reservoir has other advantages against sedimentation. Firstly, the reservoir will average about 1 km wide, less than doubling the initial river width of about 0.68 km. The slope of the initial channel within the reservoir is very steep, averaging 0.2‰, and no sediment can deposit here under natural conditions. Depending on sufficient water releases from the reservoir, these two characters could make sluicing operation for desilting the reservoir successful. Last but most importantly, the Three Gorges Reservoir has no purpose for diverting water from the reservoir into the fields, so the annual discharge after the reservoir operation will remain as sufficient as before. At these three points, it seems, at least, that the Three Gorges reservoir could not pose severe siltation problems for its normal operation and the useful life of the reservoir can not be exhausted to such an extent that the full demand for power production and flood control may not be met if application of the flushing technique is adopted properly.

B. Coastal Degradation

Coastal degradation has occurred after a few large reservoir operations. As noted previously, since 1964 the nutrient budget, biological ecology, water circulation, and hydrographic conditions have been greatly modified along the Egyptian Mediterranean coast due to the huge storage of water behind the Aswan High Dam. Especially, the sediment load carried by the Nile during the flood season, which was the main source of the two promontories of Damietta and Rosetta, has been now removed. During the past, the balance between the sediment carried away from the shore by ocean currents and the sediment supplied by the Nile seemed to favor accretion on the coast. Since erection of the high dam, almost no sediment has been discharged from the Nile, creating instability and making the entire coast vulnerable to severe erosion (Manohar, 1975). In connection with this internationally-known event in dam construction, frequently, it is naturally concluded that the runoff regulation of the Yangtze by the Three Gorges Dam, like that of the Nile by the Aswan High Dam, will produce a profound alteration in the sediment balance and biological habitat of the estuary as well as the adjacent region.

Table 3-17. Comparison of Sediment Releases between the Aswan Reservoir and the Three Gorges Reservoir

Year of Operation	Aswan Reservoir (million T)	Three Gorges Reservoir (million cu m) 150-m	160-m	170-m	180-m
Second	3.78	154.11	131.29	111.30	94.40
Fourth	2.30	157.78	134.27	113.94	96.83
Sixth	2.67	160.75	136.68	115.97	98.49
Eighth	2.71	163.33	138.83	117.70	99.77
Tenth	2.83	166.11	140.97	119.39	101.14
Twelfth	1.61	168.87	143.17	121.18	102.41
Fourteenth	2.20	171.57	144.91	122.63	103.72
Sixteenth	1.79	174.29	147.29	124.16	104.87
Eighteenth	1.92	176.99	149.39	125.77	106.09
A year prior to operation	26.27	412.75 (523 million T)			

Source: Qian, et. al., 1986.

As a matter of fact, the Three Gorges Reservoir is essentially different from the Aswan Reservoir in water-sediment discharge regulation. A substantial portion of the water in the Aswan Reservoir serves the purpose of irrigation so that no sufficient discharge releases through the dam to the estuary protect the coast against the ocean water and currents as prior to the impoundment (Fig. 2-1). However, because of no storage for irrigation the Three Gorges Reservoir can not decrease the total annual discharge releases at all, only adjusting the Yangtze's runoff below the dam in a few months (See Table 3-19). The author, according to Gill's computational procedure for estimating the loss of a reservoir capacity, found that the sediment transport through the Three Gorges Dam will be reduced by no means as dramatically as through the

Aswan High Dam (Table 3-17). In addition, the clear-water release will be able to pick up available particles from the Yangtze's silt-made bed and banks, replenishing the sediment load that is trapped by the reservoir. This erosional process in the silted channel within the middle and lower reaches of the Yangtze can also realize considerable benefits in flood control and waterway improvement.

Clear-water erosion below dams has been experienced by the Sanmenxia Reservoir. During the first four years (September 1960 to October 1964) of the operation, the sediment discharge into the reservoir was 6.76×10^9 tons, through the dam was 2.17×10^9 tons, and into the estuary of the Yellow River was 4.48×10^9 tons. Under natural conditions, the sediment discharge into the estuary was 5.07×10^9 tons per four years. This demonstrates that the reservoir operation of the first four years only reduced the amount by 0.59×10^9 tons, or 13%, of sediment transported to the estuary (Qian et. al., 1986). Apparently, the clear-water release made a great contribution to this small proportion, compensating about half of sediment deposited in the reservoir to the estuary.

Assuming that the clear-water release from the Three Gorges Reservoir could pick up one third of sediment trapped in the reservoir below the dam, the sediment discharge to the Yangtze's Estuary reduced by the impoundment is given in Table 3-18, where it is indicated that the sediment will still be sufficient so that the degradation of coastal erosion can not occur after the Three Gorges Reservoir operation. Also, comparison of sediment supply to estuaries after the Aswan Reservoir and the Three Gorges Reservoir is made in the Table 3-18.

Table 3-18. Sediment Supply to the Estuary after the Aswan Dam and Transported by the Discharge Alone through the Three Gorges Dam to the Estuary after Its Operation

Year of Operation	Aswan Reservoir (million T)	Three Gorges Reservoir (million cu m) 150-m	160-m	170-m	180-m
Second	9.04	240.32	225.11	211.78	200.52
Fourth	3.22	242.77	227.10	213.54	202.14
Sixth	4.44	244.75	228.70	214.90	203.24
Eighth	4.40	246.47	230.14	216.05	204.10
Tenth	5.08	248.32	231.56	217.18	205.01
Twelfth	3.90	250.16	233.03	218.37	205.86
Fourteenth	4.70	251.96	234.19	219.34	206.73
Sixteenth	3.32	253.78	235.78	220.36	207.50
Eighteenth	2.60	255.58	237.18	221.43	208.31
A year prior to operation	51.76	450 (Yangtze's total supply)			

Source: Qian, et. al., 1986.

Clearly, it is not acceptable to the assessment of the Three Gorges Project's environmental problems that the dam will cause the salt-water incursion and the coastal erosion in the Yangtze's Estuary as the Aswan High Dam did in the estuary of the Nile. Nevertheless, it is reasonable to take account of the effect of runoff regulation in the St. Lawrence System (Fig. 3-1) on the estuary environment as a model indicating the estuary's change resulting from the Three Gorges Project's regulation, as these two regulations have the same purpose not for irrigation but for optimum power production.

Since the turn of the century, hydro-electric power has become one of the major sources of energy to cater for increased industrialization and higher domestic electrical power consumption in Canada. For this purpose, many rivers have been utilized. Over 50% of Canadian power is produced hydro-electrically (Fig. 3-2).

Fig. 3-1 The St. Lawrence System, after Neu, 1975

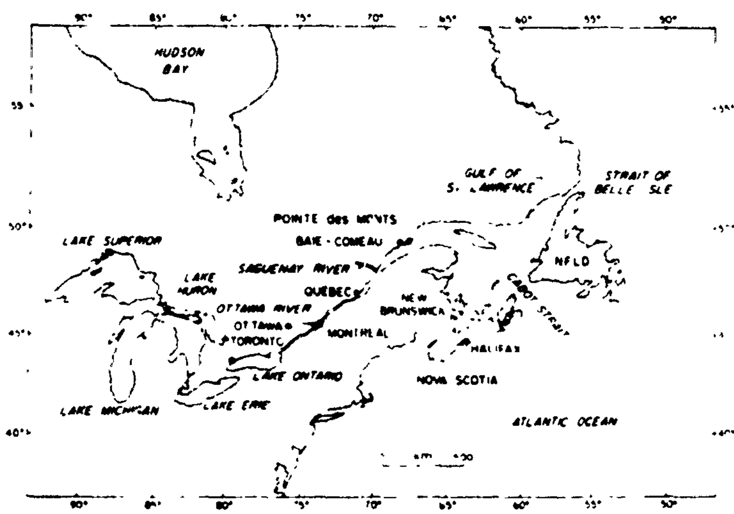
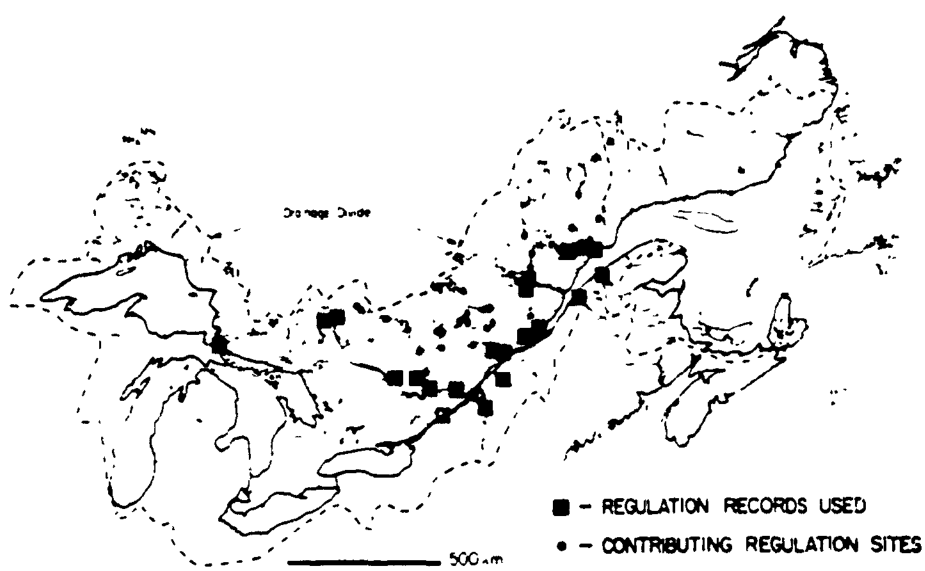


Fig. 3-2 Major Flow Regulations before the Great Lakes, after Neu, 1975



In order to optimize power output, large quantities of water from the spring runoff are retained in storage lakes and returned to the river during the low natural discharge period of fall and winter in the St. Lawrence System. It has been estimated that under present conditions the spring and summer runoff at the entrance to the Gulf of St. Lawrence has been reduced by between one third and one half (Neu, 1975). The fresh water flow to the system above Pointe des Monts has been increased artificially in February by 2500 m^3s^{-1} and decreased in May by 10,000 m^3s^{-1}. The average regulation for the period from 1963 to 1970 is given in Table 3-19, where the ratio between the monthly minimum winter discharge and the monthly maximum spring discharge are compared. The observation indicates that runoff regulation for hydro-power since the turn of the century has not caused coastal erosion but created significant consequences for the estuarine and coastal circulation pattern in the Gulf of St. Lawrence. Neu (1975), employing a theory of a haline circulation, analyses the formation of the circulation pattern in the Gulf of St. Lawrence after the runoff regulation.

Table 3-19 Average Ratio between Annual Minimum and Maximum Monthly Discharges, after Neu, 1975

	Ottawa River above Montreal	St. Lawrence River		
		Above Montreal	At Tadoussac	At Pointe des Monts
Natural	1:6.0	1:1.7	1:3.0	1:3.4
Regulated	1:2.7	1:1.3	1:1.7	1:1.8

When river water meets the ocean, a circulation is induced in the latter which the oceanographer calls a haline circulation. Two factors, the density difference between the river water and the ocean and the head needed to produce a net seaward flow of fresh water, form the basis for the large scale internal circulation by which salt water is transported into the estuary. In a long estuary, the concept of this circulation is based on a two-layer flow system in which the lower layer flows upstream while the upper layer flows seaward. The quantity of salt water circulated by this natural pumping action depends on the river discharge and the distance from the sea. Hypothetically, if the fresh water discharge were stopped completely for, say, half a year, the haline circulation would cease and the estuary would fill with sea water. On the other hand, in order to maintain the steady-state condition in the circulation, a certain amount of sea water as well as river water are continuously required. The former is transported by the circulation from the ocean into the estuary and returned to the ocean mixed with the runoff of the river.

Because of the reduction in the discharge of the St. Lawrence in spring and summer, changes have been found (1) in the salinity of the water of the surface layer: the surface layer has, since the turn of the century, increased in spring at Pointe des Monts by about 3.5‰ and in summer at Cabot Strait by 1.3‰; (2) in the seasonal strength of the haline circulation: the reduction in the quantity of sea water entering the system could exceed 150,000 $m^3 s^{-1}$ in spring and subsequently up to 2 to 3 times more in the Gulf at Cabot Strait in summer.

Like runoff regulation schemes for hydro-power in the St. Lawrence system, the Three Gorges Reservoir will trap water during the October-November high runoff season and release it during the January-May low runoff season in order to obtain more uniform flow (Table 3-20). The theory of the haline circulation therefore can be applied to predicting the effect of the runoff regulation by the Chinese reservoir on the fresh-sea water environment in the Yangtze's Estuary.

Table 3-20. Comparison of the Yangtze's Natural Discharge and the Probably Regulated Discharge (m^3s^{-1}) by the Three Gorges Reservoir at Datong

Month	Natural Discharge	Regulated Discharge 150-m	160-m	170-m	180-m
		Mean			
Jan.	10200				
Feb.	11200				
March	15200	20935	20766	20590	20987
April	23300				
May	35500				
Mean:	19080				
June	41100	41100	41100	41100	41100
July	48900	48900	48900	48900	48900
Aug.	45600	45600	45600	45600	45600
Sep.	42000	42000	42000	42000	42000
Oct.	35800				
Nov.	25200	25933	26326	26761	25879
Mean:	30500				
Dec.	14900	14900	14900	14900	14900

Source: Qian et. al., 1986.

For convenience of presentation, an estimate of the effect of the reduced river discharge can be made by focusing on a given point at which an equal quantity of seawater is added to the river water prior to the river impoundment, and hence the average salinity is about 17‰, or half of the salinity of undiluted sea water (34‰). For an example in the 150-m Scheme, during October to November, 4,567 m^3 of fresh water will be lost per second in the circulation system after the impoundment, giving place to the salt water. Therefore, the ratio of 0.85 between the fresh water and the sea water will appear instead of the initial ratio of 1:1, and the salinity in the upper layer will rise up to 18.38‰ from 17‰. On the other hand, the increase in fresh water discharge into the estuary during January-May will take over the salt water in the circulation system, diluting the sea water and hence lowering the salinity down to 16.21‰ from 17‰. The changes in salinity by the four schemes are obtained in the same process, given in Table 3-21.

Table 3-21. Estimated Changes in the Salinity at a Given Point within the Yangtze's Estuary after the Three Gorges Reservoir

Typical Scheme	Decrease during January-May		Increase during October-November	
	Salt/Fresh Water Ratio	Salinity (‰)	Salt/Fresh Water Ratio	Salinity (‰)
150-m	0.10	0.79	0.15	1.38
160-m	0.09	0.72	0.14	1.25
170-m	0.08	0.65	0.12	1.10
180-m	0.10	0.81	0.15	1.39

The reduction in the fresh water discharge into the estuary, such as that caused by the Three Gorges Reservoir, could create a lower water head which is insufficient to produce a seaward flow of fresh water as large as before. This modification not only increases salinity in the upper layer but also decreases the strength of the haline circulation in the meantime. Again, taking a given point at which the ratio between fresh water and sea water is 1:2, or a salinity of 22.7‰, as an example, and assuming that the fresh/salt water circulation remains constant at the point, an estimate of the effect of the reduced river discharge by the 150-m Scheme on the quantity of salt water involved can be made: (1) a reduction of 4,567 m^3s^{-1} in the October-November discharge will decrease the inflow of the sea water to the estuary by 9,134 m^3s^{-1}; and

(2) on the other hand, the river discharge will be augmented by about 1,855 m^3s^{-1} during January-May so that this must increase the flow of salt water into the estuary by 3,710 m^3s^{-1}, or 9.7% above the natural conditions. The changes in the flow of sea water caused by all four schemes are given in Table 3-22.

Table 3-22. Estimated Changes in the Haline Circulation at the Given Point within the Yangtze's Estuary after the Three Gorges Reservoir

Typical Scheme	Flow Increase during January-May (cu. m/s)		Flow Decrease during October-November (cu. m/s)	
	River Water	Sea Water	River Water	Sea Water
150-m	1855	3710	4567	9134
160-m	1686	3372	4147	8294
170-m	1510	3020	3739	7478
180-m	1907	3814	4621	9242

These changes must result in significant impacts on the marine biology in the estuary of the Yangtze and the offshore region. A reduction in circulation and upwelling during October-November could decrease the nutrient supply from the deep water of the ocean to the upper layer, which is referred to by biologists as the "life layer". This in addition to the change in salinity composition of the water of the upper layer, must affect the reproduction of many species of fish and thus the structure of the biomass of the region. In fact, Sutcliffe (1972, 1973) compared fish catches in the Gulf of St. Lawrence with long-term (10-20 years) variation in the fresh water runoff and inferred from the results that for certain species, there is a close correlation between the the two: the larger the runoff the greater the yield.

CHAPTER IV

ENVIRONMENTAL PLANNING FOR THE PROJECT

The major environmental impacts of the Three Gorges Project have been analysed in detail in the last chapter, but it is still difficult to evaluate the net environmental effects of the project and hence to make trade off in selecting among the alternatives because properties of the environment are not commonly measured in commensurate units. However, the environmental evaluation system (EES) discussed in chapter II could make the trade offs possible.

The EES can be applied in the evaluation of project impacts to select specific alternatives and in the planning process to minimize potential adverse impacts in future projects. When the EES is applied only to screen alternatives, the information obtained is normally not used to modify a project. However, when the EES is applied in the planning process, a feedback loop is used to continually modify the project through successive interactions of the development process. Projects development with the assistance of the EES could be expected not only to avoid adverse environmental impacts but also to improve selected portions of the environment. Based on the analyses done in the last chapter, the EES as a methodology will be applied in the environmental planning of the Three Gorges Project.

4.1 SELECTION OF ENVIRONMENTAL PARAMETERS

Parameters represent key features of the activities involving description of the environmental setting, impact production and assessment, and selection of the proposed course of action. Appropriate selection and use of parameters is an important component of the environmental impact assessment process. For the six major environmental impacts of the Three Gorges Project, parameters are selected as in Table 4-1.

Table 4-1. Selection of Environmental Parameters for the Three Gorges Project

Environmental Impact	Environmental Parameter
Flood control	Reservoir capacity for flood storage
Power production	Annual average power production
Navigation improvement	Reservoir waterway creation
Population displacement	Number of inhabitants requiring relocation
Destruction of fish habitat	Coefficient of reservoir water circulation
Reservoir siltation and Coastal degradation	A) Mean rate of reservoir capacity loss during its half-filled years B) Increase in salinity C) Decrease in sea water inflow

All the parameters described above could cover the selected major environmental impacts of the Three Gorges Project. Reservoir capacity for flood control and the number of inhabitants requiring relocation are related to the human environmental impacts; annual average power production and reservoir waterway creation reflect the

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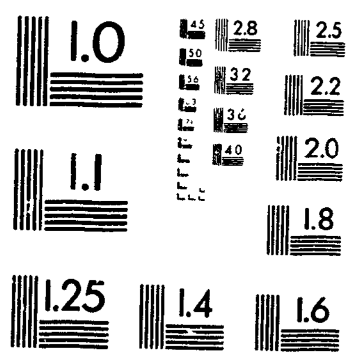


economic environmental impacts; the coefficient of reservoir water circulation which determines the temperature of release water, a dominant limiting condition for fish species, is associated with the biological environmental impacts; all three parameters relating to the last item express the physical environmental modifications. Certainly, these parameters are insufficient for covering all environmental problems of the Three Gorges Project, but they will enable a comprehensive consideration of and planning for the dominant environmental consequences of the project's development.

4.2 VALUE FUNCTION DESIGNS

Each environmental parameter represents a unit or an aspect of environmental significance worthy of separate consideration in water resource development. In order to demonstrate the net environmental effects of a project, all parameters need to be transformed into environmental quality (EQ) in commensurate units through the use of a value function that represents an empirical relationship between objective measurements of a parameter and a subjective evaluation of the quality (good or bad) of that parameter in the environmental setting. Objective measurements are plotted on the X-axis, while the subjective quality index is presented on the Y-axis. The quality index is graded on a scale from 0.0 to 1.0 with 0.0 representing low or undesirable quality and 1.0 representing high or desirable quality.

Almost all environmental impacts of dam construction are closely related to the reservoir scale. Both the beneficial and adverse parameters are proportional to the storage capacity of a reservoir or the height of a dam. For instance, if the height of a dam increases, the amount of hydro-power production, the number of displaced persons, the capacity for controlling floods, the reduction in release water temperature, resulting from the project will increase correspondingly. This suggests that the height of a dam should be the most significant factor indicating the magnitude of each parameter.

Of course, the minimum height of a dam is 0; there must also be a realistic maximum height for a dam on any particular section of rivers. A dam of the minimum height creates no beneficial or adverse impacts on the environment, while a dam with the maximum height could result in maximum magnitudes for every parameter. A given height of a dam produces proportional effects.

For the Three Gorges Project, the maximum height of the dam was set at 180 m, as stated earlier, which could keep Chongqing just above the inundating line. Therefore, it is reasonable to assume that each environmental parameter will reach its upper limit (representing desirable quality or undesirable quality) if the Three Gorges Project is built according to the 180-m Storage Scheme. As the normal water level behind the dam increases from 0 to 180 m, each value of beneficial and adverse environmental parameters increases from 0.0 to 1.0 respectively. From this observation, the value functions for all selected environmental impacts could be obtained, as shown in Fig. 4 Fig. 4-8.

All functions are linear except the one for destruction of fish habitat, which is associated with the coefficient of reservoir water circulation. Experience indicates that cold water release through a dam occurs if the coefficient is less than 10, but not if the coefficient is greater than 20 (Hu, 1986). The function for destruction of fish habitat is designed to reflect this experience.

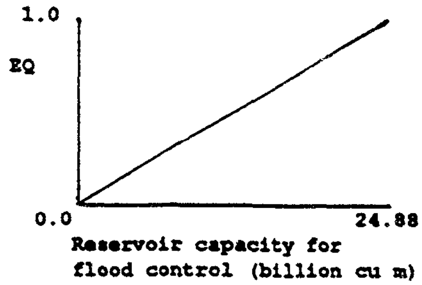


Fig. 4-1 Flood Control

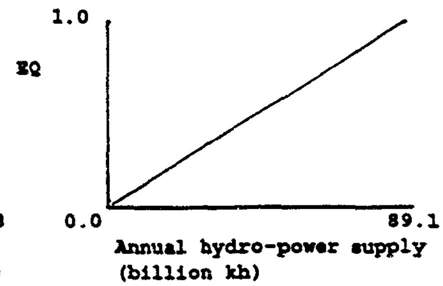


Fig. 4-2 Power Production

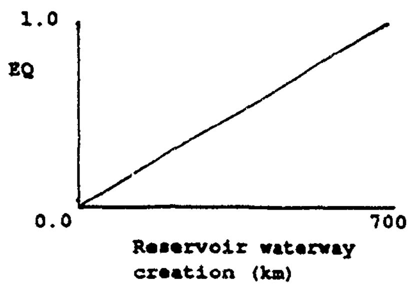


Fig. 4-3 Navigation Improvement

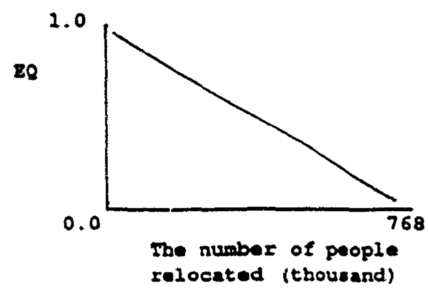


Fig. 4-4 Population Displacement

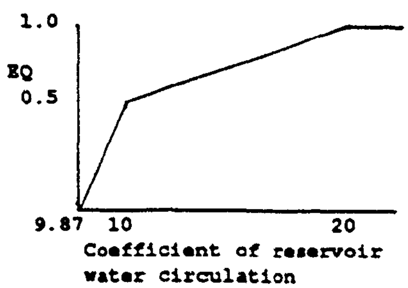


Fig. 4-5 Destruction of Fish Habitat

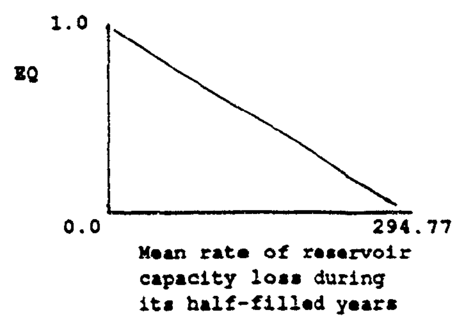


Fig. 4-6 Reservoir Siltation

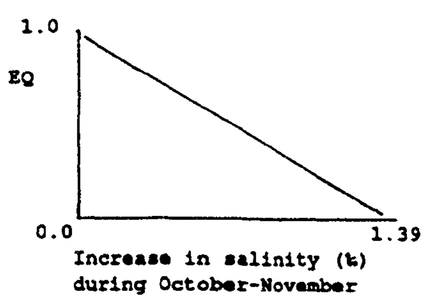


Fig. 4-7 Coastal Degradation (A)

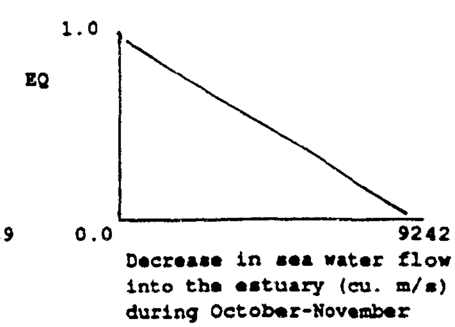


Fig. 4-8 Coastal Degradation (B)

4.3 ENVIRONMENTAL QUALITY ANALYSES

Using the selected environmental parameters as well as their value functions makes quantitative environmental quality analyses of the Three Gorges Project possible. The analyses consist of (1) evaluating the expected future condition of environmental quality "without" the project, and (2) evaluating the predicted condition of environmental quality "with" the 150-m, 160-m, 170-m, and 180-m Storage Schemes respectively (Tables 4-2 and 4-3). The objective of the analyses is to make trade offs between human, economic, biological, and physical environmental parameters in the development of the project.

Table 4-2. The Environmental Quality "without" the Three Gorges Project

Environmental Impact	Environmental Parameter	Parameter Scale	Environmental Quality
Flood control	Reservoir capacity for flood storage (billion cu m)	0.0	0.0
Power production	Annual average hydro-power production (billion kh)	0.0	0.0
Navigation improvement	Reservoir waterway creation (km)	0.0	0.0
Population displacement	Number of inhabitants requiring relocation (thousand)	0.0	1.0
Destruction of fish habitat	Coefficient of reservoir water circulation	maximum	1.0
Reservoir siltation and coastal degradation	A) Mean rate of reservoir capacity loss during half-filled years	0.0	1.0
	B) Increase in salinity (‰) during Oct.-Nov.	0.0	1.0
	C) Decrease in sea water flow into the estuary during Oct.-Nov. (cu. m/s)	0.0	1.0

Table 4-3 The Environmental Quality "with" the Three Gorges Project

Environmental Impact	Environmental Parameter	Parameter Scale				Environmental Quality			
		150-m	160-m	170-m	180-m	150-m	160-m	170-m	180-m
Flood control	Reservoir capacity for flood storage (billion cu m)	22.0	22.0	19.7	24.88	0.88	0.88	0.79	1.00
Power production	Annual average hydro-power production (billion kh)	66.7	73.2	78.5	89.1	0.75	0.82	0.88	1.00
Navigation improvement	Reservoir waterway creation (km)	550	600	650	700	0.79	0.86	0.93	1.00
Population displacement	Number of inhabitants requiring relocation (thousand)	330	422	622	768	0.57	0.45	0.19	1.00
Destruction of fish habitat	Coefficient of reservoir water circulation	22.85	17.18	13.08	9.87	1.00	0.72	0.32	0.00
Reservoir siltation and coastal degradation	A) Mean rate of reservoir capacity loss during half-filled years (million cu. m/y)	230.56	254.86	276.08	294.77	0.22	0.14	0.06	0.00
	B) Increase in salinity (‰) in the given point during Oct.-Nov.	1.38	1.25	1.10	1.39	0.01	0.10	0.21	0.00
	C) Decrease in sea water flow into the given point of the estuary during Oct.-Nov. (cu. m/s)	9134	9294	7428	9242	0.01	0.10	0.20	0.00

To reflect the net environmental impact of the Three Gorges Project all the parameters must be assigned a relative weight, although it is impossible for the present study to use sociopsychological scaling techniques and the Delphi procedure to quantify the value judgements. Clearly, some parameters are much more important than others. Based on the analyses in Chapter III, the environmental impacts could be divided, according to the degree to which the Three Gorges Project would disturb or enhance the dynamic stability of human, economic, biological, and physical environments, into two groups: 1) flood control, power production and population displacement; and 2) navigation improvement, destruction of fish habitat, and reservoir siltation and coastal degradation.

```
                        ________________________
                       | Environmental Impacts |
                        ------------------------
                                   |
      _____________________________|_______________________________
      |                |                   |                   |
  ____|____     _______|_______     _______|_______     _______|_______
 | Human  |   |   Economic    |   | Biological    |   |   Physical    |
 |  [2]   |   | [1.25-1.75]   |   | [0.25-0.75]   |   | [0.25-0.75]   |
 |--------|   |---------------|   |---------------|   |---------------|
      |                |                   |                   |
 _____|__________  ____|___________  ______|__________  _______|_______
| Flood          || Hydro-power    || Destruction of || Reservoir      |
| control (1)    || production     || fish habitat   || siltation      |
|                ||      (1)       || (0.25-0.75)    || and coastal    |
| Population     ||                ||----------------|| degradation    |
| displacement   || Navigation     |                  | (0.25-0.75)    |
|      (1)       || improvement    |       Legend     |----------------|
|----------------|| (0.25-0.75)    |  [ ] Total
                  |----------------|  ( ) Parameter Importance Units
```

Fig. 4-9 The Environmental Evaluation System for the Three Gorges Project

Apparently, the environmental impacts of group one are much more important than those of group two. Therefore, each of the former is assigned a relative importance of 1, while each of the latter is assigned a relative importance of 0.25-0.75, reflecting the different perspectives on the project construction. In other words, the ratio between the importance of environmental impact measurements in group 2 and in group 1 is 0.25-0.75. So far the en·ironmental evaluation system for the Three Gorges Project could be established as in Fig. 4-9.

Using this system and the environmental equality indices as well as the following model discussed in Chapter II,

$$E_I = \sum_{i=1}^{(i=m)} (V_i)_1 W_i - \sum_{i=1}^{(i=m)} (V_i)_2 W_i \qquad (2\text{-}1)$$

a total score in commensurate units termed "environmental impact units" (EIU) "without" and "with" each of the four selected schemes for the Three Gorges Project was produced as the total and net environmental impacts respectively of the projects, given in Table 4-4 and Fig. 4-10.

Fig. 4-10 Tradecffs among Four Projects

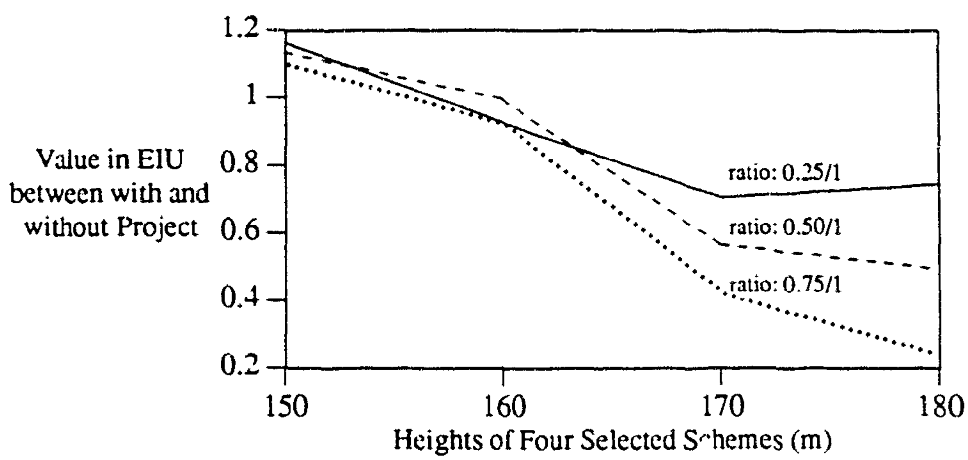


Table 4-4. EES Summary for the Three Gorges Project:
Value of Environmental Quality in EIU

Environmental Impact	Environmental Quality without Project	Environmental Quality with Project			
		150-m	160-m	170-m	180-m
Flood control	0.00	0.88	0.88	0.79	1.00
Power production	0.00	0.75	0.82	0.88	1.00
Navigation improvement	0.00	0.79	0.86	0.93	1.00
Population displacement	1.00	0.57	0.45	0.19	0.00
Destruction of fish habitat	1.00	1.00	0.72	0.32	0 .00
Reservoir siltation and coastal degradation	1.00	0.08	0.11	0.16	0.00
Value in EIU					
A. Using 0.25 ratio	1.50	2.67	2.43	2.21	2.25
B. Using 0.50 ratio	2.00	3.14	3.00	2.57	2.50
C. Using 0.75 ratio	2.50	3.60	3.42	2.92	2.75
Value in EIU between with and without project					
A. Using 0.25 ratio		1.17	0 93	0.71	0.75
B. Using 0.50 ratio		1.14	1.00	0.57	0.50
C. Using 0.75 ratio		1.10	0.92	0.42	0.25

At the conclusion of the evaluation, in terms of the net environmental impacts of the Three Gorges Project, the results indicate that (1) the 150-m Storage Scheme is the best one among the four alternatives, (2) each of the four is able to create more beneficial impacts than adverse ones on the environment, and (3) between 150 m and 180 m, the lower the normal water-level behind the dam the better the environmental quality.

CHAPTER V

CONSIDERATIONS FOR THE PROJECT DEVELOPMENT

> "What is urgently needed is the formulation of long-term development policies, on a sustaining basis, that reflect changing water supply and demand patterns, consistent with efficient use, and better undertaking of social and environmental implications, so that adverse impacts can be minimized"
>
> A. Biswas, 1978

It could be well argued that some reservoirs exemplify the successful enhancement of environmental quality of Man's modification of river systems; however, from the geographical point of view, their beneficial and adverse impacts emerge in different sections of the river system. Quite often, reservoir areas are hazard-concentrated, while the benefit from the project extends far away. At this point, large water resource development projects, such as the Three Gorges Reservoir, could not be considered a geographically-just event. In order to overcome this unfairness, benefits from the project must be given to those who used to live in the reservoir area in another way, and much care should be taken with such a hazard-concentrated area prior to the project development.

5.1 GEOGRAPHICAL IMPLICATIONS OF THE THREE GORGES PROJECT

Regionally, the distribution both of benefits and hazards resulting from a large-scale impoundment is remarkably non-uniform. Reservoir areas provide suitable conditions for most of the hazards so that they receive much higher density of the hazards, while the hazard density outside of the reservoir area is lower. Generally speaking, there is a hazard-benefit pattern of large-river impoundments within the river system.

The hazard-benefit pattern of the Yangtze's impoundment is described in Fig. 5-1. Apparently, hydro-power production and flood control will benefit the regions downstream: South-Central China and East China, but at the cost of the relocatees' homeland and at the risk of the other hazards in the reservoir area. The people living here will be affected most adversely; they obtain few benefits directly from the project.

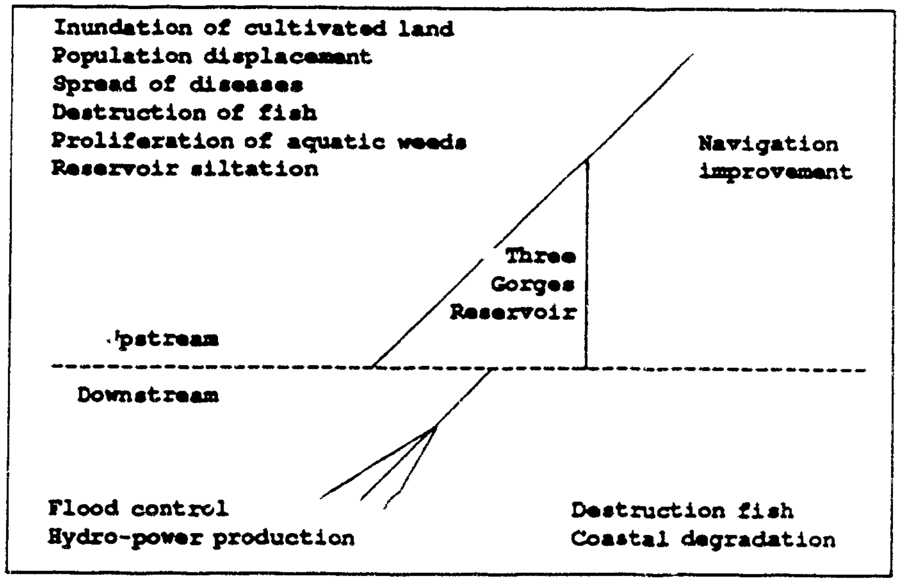


Fig. 5-1 A Hazard-Benefit Pattern of the Three Gorges Project

Developers of the Three Gorges Project must keep the geographical characteristics of the impacts in mind during the present planning stage as well as the later operation period. Emphasis should be placed on how to give compensation to the relocatees and how to deal with the other hazards in the reservoir area because the achievement of the project is largely dependent on these issues. Also, it is strongly suggested that the benefits from the project should be redistributed by the developers through appropriate social programs.

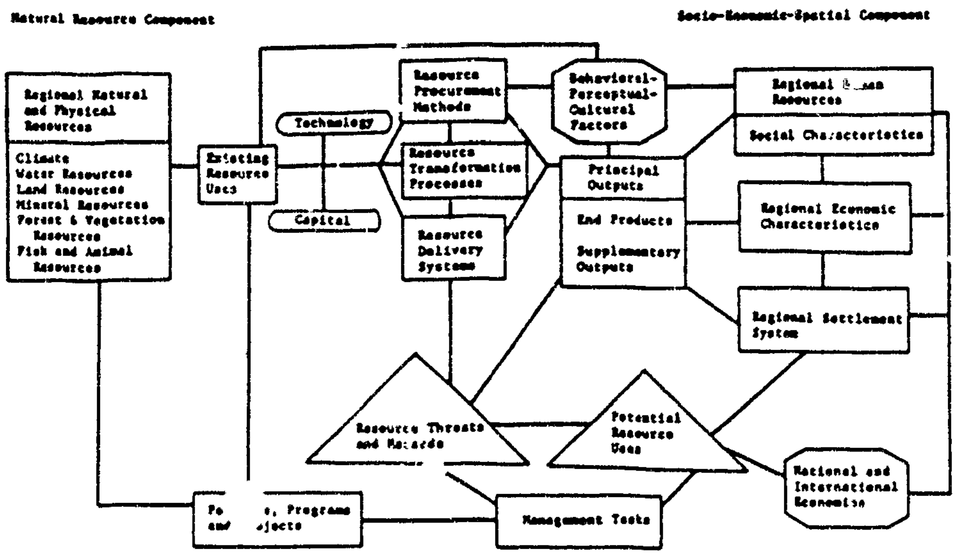
5.2 SOLUTION TO POPULATION DISPLACEMENT

Population displacement from the reservoir area poses the most crucial obstruction to the Three Gorges Project. The project can not be built until this obstruction is removed. Certainly, the relocatees will lose their support resources--cultivated land--with the appearance of the lake, which could provide new support resources, or so-called benefits for other regions. The essence of the question is whether new support resources could be available for the relocatees, or in other words, whether the benefits from the project could be allotted to the displaced population. The answer will be given in the following discussion, with the aid of an applied method of regional development.

5.2 1 Regions as Integrated Resource-Human Settlement Systems

All natural and social systems exist in geographical space. Resource systems within regions are inextricably linked; the location of projects can have a fundamental impact on resource system interactions and the well-being of the human population. The impact can be analysed effectively only if planning is done at a regional level (Ruddle et. al., 1983). Regional analysis and planning provide a geographical focus through which to analyse the complex interactions within the resource systems and are thus essential elements of development policy-making.

Fig. 5-2 Regions as Integrated Resource-Human Settlement Systems, after Ruddle and Rondinelli, 1983



A region, in which resources, production and human settlement are interacting forces in regional development, has been described as an integrated resource-production-human settlement system (Fig. 5-2) by Ruddle and Rondinelli (1983). "As a combination of resource, production and human elements that provide for human needs, the system consists of entire chains of events through which a component of the general environment is perceived as a resource and passes from its source through processing or technological transformation to the creation and delivery of an end product that satisfies a perceived human need" (Ruddle & Rondinelli, 1983). In the concept of regional development natural resources must be procured and transformed into productive goods, and delivered to internal and external markets. The way in which a region's natural resources are transformed depends not only on the application of technology and capital but also on behavioral, perceptual and cultural factors, social characteristics of the human population, regional economic factors, and the pattern of settlement and interaction (Rondinelli, 1985).

As an integrated resource-human settlement system, the Yangtze Basin is proposed to receive an input--the Three Gorges Project. As a result, two principal outputs--hydro-power production and population displacement--will be generated. In other words, the water resources and land resources within the region will be transformed into a hydro-power resource. This must affect the region's economic characteristics and the particular area's population settlement. From the whole regional beneficial point of view, the project is necessary, and developers should make appropriate policy for executing management tasks. In my opinion, the focus of the policy should be placed on the power production, which could create new support resources for relocatees provided suitable management policies are available.

5.2.2 Dams as Tools Transforming Support Resources

Within a region of integrated resource-human settlement systems, dams and their resultant reservoirs destroy the support resources of those who live in the project areas but also create other new support resources elsewhere. The operation of large dams, such as the Three Gorges Dam, serving mainly as electricity production, could result in industrial development as well as creation of employment opportunities, which are regarded as new support resources. As a matter of fact, the experience of the industrial development in the Tennessee Valley Authority area indicates explicitly the relationship between increase in power production and in employment (Table 5-1).

Table 5-1. Industrial Development within the Tennessee Valley Region: Increase in the Demand for Electricity and New Jobs Created during 1968.

Industry	Increase in Kilowatt	Increase in Employment	Increase in Electricity Demand Per Job (kilowatt hours)
Food and related products	9,920	1,371	7
Textile mill products	57,945	5,302	10
Clothing and finished fabric	9,643	5,707	1
Paper and allied products	26,410	1,323	19
Chemical and allied products	115,060	2,334	49
Rubber and miscellaneous plastic products	20,145	1,835	10
Stone, clay and glass products	17,225	1,985	8
Primary metal	91,510	2,340	39
Fabricated metal products	20,875	3,205	6
Machinery except electrical	20,635	3,590	5
Electrical machinery	14,585	4,265	3
Transportation equipment	11,725	3,443	3
	Average increase in electricity demand per new job (kilowatt hours):		13.3

Source: Industrial Development in the TVA Area during 1968, Tennessee Valley Authority, Division of Power Marking, Chattanooga.

On the average, a 13.3 kilowatt hour electricity increase can create one new job in the Tennessee Valley Authority area. If this rate could be adopted, it seems that the problem of displaced population posed by the Three Gorges Project could be solved partly by the dam itself. The project, whose proposed annual electricity supply would be 66.7, 73.2, 78.5 or 89.1×10^9 kilowatt hours, could probably create 572,493, 628,283, 673,773 or 764,754 new jobs according to the four schemes respectively, the first three of which are much more than 330,000, 422,000 and 622,000, the numbers of persons displaced by the corresponding projects; the last one is not more than 768,000 of the number but quite close to that.

It is suggested, therefore, that new settlements not be the only places for evacuees to move into, and that through government policies some of the evacuees be employed in the industrial areas dependent upon the power supply of the project. In this way, evacuees could gain benefits from the project, instead of suffering. Of course, it is impossible to provide employment for all the relocatees; new settlements for the rest of the relocatees are necessary as a supplementary solution, but the benefits from the project should be allotted to the settlements at the same level. In addition, the following stages proposed by Takes (1973) are adopted here for the population displacement from the reservoir area to new settlements.

1. Preparation. The first step is to define the exact future maximum lake margins in order to find how many and which people need to be evacuated. A new census should then be taken for the purpose of registering the occupations of these people, their family structure, and titles to and value of their land, houses, fruit trees, and other immovable properties. As far as possible, compensation should be given in kind, e.g. by providing farmers with good new farmland in advance to enable them to continue their farming activities immediately after arrival in the settlement area. In the

selection of suitable resettlement sites, the following factors should be taken into account: quality and irrigability of the soil, location and accessibility of the area, tenurial status of lands, size of the sites, degree of existing inhabitation, availability of water for drinking and household purposes, health considerations, and availability of indigenous materials for village industrial and household purposes. Also, in the preparatory stage, early attention should be given to proper planning of the resettlement areas, and to the organization and administration of the resettlement activities.

2. Transfer. It is essential that the transfer of reservoir inhabitants to the resettlement area be planned carefully. The best time for moving to the new farm is after the farmers have harvested their crops. They can then take the largest possible supply of foodstuffs with them and can start preparing the new land for the next farming season.

3. Development. Assistance to the resettler resettlement should be continued for several years, particularly to help them organize a number of necessary institutions in the economic, social and cultural fields, such as the distribution of water and the maintenance of the irrigation works on the field level; supply of seeds, seedings, fertilizers, insecticides, and other agricultural inputs; processing and marking of produce; provision of rural credit; training in handicraft; and community centres, women's and youth groups, adult education classes.

4. Evaluation. As all aspects of resettlement should be directed toward development, it is of the outmost importance that progress be evaluated periodically. Such an evaluation should not merely aim at discovering what impact the project has

on the economic position of the resettled population, as measured by the criterion of per captia income, but should include the achievements as well, such as the improvement of social institutions, the success of efforts to stimulate cooperation between different government agencies, the degree of adaptation of resettlers to the new environment and way of living, and the fusing of different population groups into a new community. Apart from this evaluation of a resettlement project as its implementation proceeds, a long-term evaluation of the socio-economic impact of the project should be undertaken before it is finally integrated into the national systems.

5.3 RECOMMENDATIONS FOR OTHER FUNDAMENTAL ISSUES

Besides the population displacement, the Three Gorges Project will generate adverse impacts, major as well as minor, on fish species upstream and downstream, on the environment of its resultant lake and th surrounding areas, and on the marine biology in the estuary of the Yangtze and the offshore region. These far-reaching consequences of damming such a large river seem to be inevitable; however, they all could be minimized with the aid of certain environmentally-sound measures. The control of them is advisable in all cases, and essential in many.

5.3.1 Maintenance of Fish Species

The impoundment of the Yangtze by the Three Gorges Dam poses two major detriments to fish species: firstly, the creation of the reservoir according to any one of four selected schemes greatly increases the travel-time of the water through the system so that thermal stratification and hence cold-water release may occur during spring and summer; secondly, the construction of the dam provides a destructive barrier to anadromous fish migration downstream and upstream.

In an attempt to retain pre-impoundment water conditions, selected withdrawal techniques have proved feasible in most cases. The provision of multiple-level drawoff points to facilitate selective withdrawal is seen as the simplest but the most effective method of controlling water-temperature. The effectiveness of value releases is well demonstrated by Gore (1977). Operational requirements of the Tongue River Reservoir Dam, Montana, USA, resulted in the control gates of the dam remaining open for most of spring and summer of 1975. The continual high release of water prevented thermal stratification, so that the water quality of the release returned to pre-impoundment conditions. Below the dam, discharges were observed to have temperatures only negligibly cooler than at the mouth of the river, and the diurnal and monthly thermal fluctuations approached those expected for non-regulated streams. The use of selected-depth releases may therefore be beneficial.

Dam construction will also adversely affect the rate of fish migration, and the availability of suitable channel-reaches for spawning, so that the number of valuable fish will be reduced. In order to improve the management of fisheries for anadromous species, plans have involved considerations of three major operations stated by Petts (1984, p. 231-235): fishway construction, fish collection and trucking, and the creation of artificial spawning-grounds.

1. Fishway. In order that fish may circumvent the blockages to migrations that are imposed by large dams, "fishways" have commonly been constructed. These allow fish to bypass the dam, and so provide continuity between fish populations along the river.

Fish "ladders" generally consist of a long sequence of wires and pools, starting from the tailwater below the dam and ascending in small increments until reaching the water level of the reservoir. Such fishways often provide adequate access for salmo and trout over low-head structures (Long and Krema, 1969). The design and efficiency of fishways past high-head dams is dependent upon a detailed knowledge of the swimming capabilities and behaviour of migration fish, particularly in relation to the discharge and water quality requirements for movement to be induced. For the high-dam of the Three Gorges Project, this fish knowledge should be provided in the present planning stage.

2. Collection and Transportation Facilities. For avoiding the mortality and the hazard of delayed migration imposed by slow passage through reservoirs and fishways, particularly where a long series of impoundments are involved, upstream and downstream transportation by truck or barges has been employed, together with specialized fish-collection facilities (Long and Krema, 1969). The collection and trucking of juveniles for downstream release may also have advantages by reducing losses from turbine passage. A 300-km trucking system on the Columbia River, for example, increased survival rates, in comparison with these of natural migration, by up to 35% during periods of high-spillage, and by 64% for periods before major spillweir discharge (Trefethen, 1972).

3. Artificial Spawning-Grounds. The loss of spawning-ground is primarily related to the isolation by the dam. In many rivers where impoundment is likely to produce major losses of breeding grounds, artificial spawning-channels are being used with increasing frequency and success, to ensure that fish populations are maintained

(Geen, 1974). Artificial spawning-channels provide both regulated flow and optimum substrate-size for the eggs of particular species that are reared. The survival of eggs and alevins under such controlled and protected conditions is often substantially above that observed within natural rivers, giving from two to nine times the egg-to-fry survival of a natural river. The Weaver Creek spawning channel, Harrison Creek, Canada, has been utilized annually by between 18,000 and 27,000 spawners in recent years, and has given an egg-to-fry survival of 61-81%: this is nine times more efficient per unit area for the production-returning adults than natural spawning-grounds, producing 148,952 and 194,744 returning *Oncorhynchus* in two consecutive years (Mundie, 1979). Furthermore, artificial spawning-channels have been used to increase salmon populations in areas that are unaffected by impoundments (Mackinnon et al., 1961).

5.3.2 Desiltation Operation

Reservoir siltation creates major problems in planning, design and operation of water resource systems. The useful life of a reservoir can be reduced rapidly because of high sediment yields from drainage basins. The Three Gorges reservoir, with the storage capacity of $19.69\times10^9\ m^3$ or more, has been estimated to have a useful life of between 42.7 and 75.6 years if the time that a reservoir has lost 50% of its capacity is the criterion of its useful life. However, most hopefully, the useful life of the Three Gorges Reservoir can be substantially increased conditional upon applications of desiltation operation techniques.

1. Sediment Flushing. It has been demonstrated that, although applications of the

flushing technique have so far mainly been for relatively small capacity reservoirs (with capacities of less than $100 \times 10^6\ m^3$), the technique is now proving successful in large reservoirs, for example in China and the USSR (Paul and Dhillion, 1988).

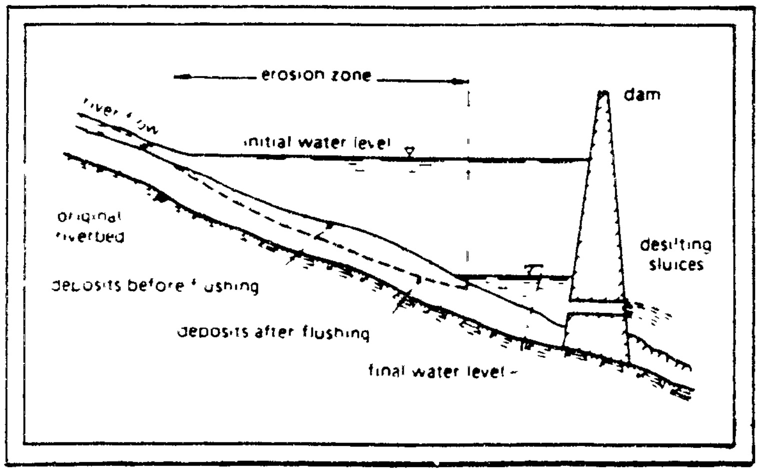


Fig. 5-3 Hydraulic Flushing of Reservoir Sediment (Paul et. al., 1988)

The hydraulic flushing of sediment deposits through low-level sluices (Fig. 5-3) is one successful solution to reservoir sedimentation. When the desilting sluices are opened, the water level in the reservoir begins to fall, and an unsteady flow towards the sluices is generated. This flow entrains the sediment particles from the deposits and transports them towards the sluices. During this process, a channel with gradually expanding dimensions is formed as the flow cuts its path through the thick deposits, thereby restoring the reservoir storage capacity. The Three Gorges reservoir having a relatively narrow and steep bottom must favour this process. According to Paul and Dhillion (1988), flushing will prove more effective by the following conditions:

1. the lower the head on the sluices;
2. the greater the discharge available;
3. the wider the sluices;
4. the deeper the setting of the sluices;
5. the longer the duration of flushing; and
6. the steeper the bottom slope.

Also, it is suggested that:

1. flushing should take place at least once a year;
2. the flushing operation should begin when sediment deposits are less than 100-200 m from the dam;
3. the period of flushing should take into account the time required for subsequent filling;
4. the flushing sluice operation should be intermittent; and
5. flushing should be carried out under free-flow conditions.

Besides, the shape and area of sluices play an important part in the hydraulic flushing. Paul and Dhillion, based on most experiences in the world, found that the optimum height of the sluice is 1.5 to 2.5 m, and provided the curve in Fig. 5-4 for selecting the dimensions of flushing sluices in relation to the initial or design capacity of reservoirs and the average annual sediment inflow rate. Thus, the required sluices area (as read from Fig. 5-4) should be obtained by increasing the width other than the height. If the area calculated is too large for a single sluice, then several identical sluices should be chosen. Considering the annual sediment inflow into the Three Gorges Reservoir, the preferable area of sluices approximately is 200 m^2.

2. Venting. Sluicing operations are effective for flushing sediment that has already settled in the vicinity of the sluice intakes, while venting operations refer to the adoption of outflow gates, often synchronized to intercept density-currents, to "waste" silt-laden flood water that is underrunning the reservoir. Density-currents, for example, have been used to evacuate accumulated sediment, and maintain storage capacity.

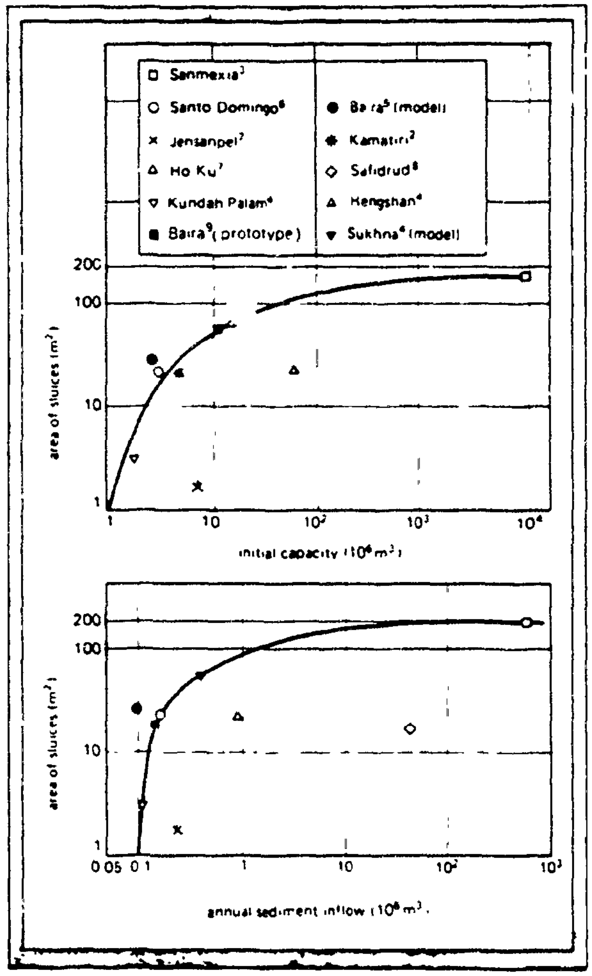


Fig. 5-4 Suggested Design Curves for Flushing Sluices (Paul et. al., 1988)

The operation of outlet gates during flood inflows could produce the venting between 10% and 25% of incoming sediment, without adversely affecting water storage in the reservoir (Brown, 1944). Rausch and Heinemann (1975) advocated the use of bottom withdrawals to decrease the retention time, by discharging storm-runoff density currents, while retaining the clear water which "floats" above. Bottom withdrawals increase sediment releases, both by reducing the retention time and by eliminating the "dead" storage capacity, so that only the coarse sediment particles, deposited in deltaic inflow area, will be trapped. The Three Gorges Reservoir is suitable to the venting operation: in general, it will release all inflow water during the period of the high water level.

5.3.3 Prevention of Coastal Degradation

Coastal degradation resulting from large-scale impoundments means the coastal erosion and fresh/salt water alternation in the river mouth. For the mouth of the Yangtze, provided that the sedimentation in the Three Gorges Reservoir can be prevented as discussed earlier in the current chapter, the Yangtze is able to supply sufficient material to maintain the previous delta, or at least, an imbalance in the near-coast sediment budget seems not to emerge after the project. However, increase in salinity and decrease in seawater inflow during October-November, as a result of regulating discharge, needs to be considered in particular ways. Probably, turning to the Yangtze System for solution is best.

The Yangtze System has such an advantage--a distribution of numerous lakes along its middle and lower courses--that its runoff can be regulated by the system itself as much as by man-made projects. The most spectacular lake group is the Ancient Yunmeng Swamp Area in China's so-called East Lake Region. Especially the middle section, located from Yichang to Wuhan, is essentially a lake-basin plain with an area of about 80,000 km^2, one eighth of which consists of lakes.

Automatically, the lakes have a strong influence upon regulating both the natural and man-regulated runoff of the Yangtze. In being scattered over the southern courses, they receive a large portion of the flood runoff of the river, including the man-made floods such as heavy release from the reservoir, and then return it to the river after its level has fallen. The exceptional function of this water reservoir provides not only for preventing inundation but also for increasing or decreasing the man-regulated runoff appropriately. The existence of the latter regulation has barely been recognized in recent studies, but it is essential to keep the fresh/salt water ratio as close to the pre-impoundment conditions in the coastal area of the Yangtze as possible.

Among many lakes, the largest now is Poyang Lake (See Fig. 1-1) with an area of 3,583 km^2, also being the largest freshwater lake in China. The second largest is Dongqing Lake (See Fig. 1-1) with an area of 1,840 km^2, formerly a part of the extensive Yunmeng Swamp Area and the largest freshwater in China. Both of them are downstream of the site of the Three Gorges Dam, characterized by low elevation and shallow water being mostly less than 4 m in depth.

Dongqing Lake is connected by five channels with the Yangtze, over four of them the river water enters the lake, and over one, at Yueyang, the lake waters return to the river. Over the year Dongqing lake receives about 40% of runoff of the Yangtze, increasing this index up to 60% during the flood period. The total discharge of all four channels where they flow into Dongqing Lake is an annual average of 7,136 m^3s^{-1}. With the high level in the Yangtze, the overflow of the river water is significant.

Especially in the period from June through October it provides 84% of the annual supply. The maximum amount of discharge (18,600 $m^3 s^{-1}$) in the channel is reached in July and the minimum amount (200 $m^3 s^{-1}$) in January (GI, 1969, p. 153-154).

Considering the regulating function of Poyang Lake and Dongqing Lake with a total area of 5,423 km^2, it could be concluded that the problem of fresh/salt water alternation caused by the Three Gorges Project can be partly prevented depending upon the proper operation of these two large lakes. The Three Gorges Reservoir will increase and reduce the discharge of 24.07, 22, 19.7, or 24.48 km^3 downstream during January-May and during October-November respectively. Therefore, in order that the fresh water flow into the Yangtze's estuary remains the same, or is re-regulated, as prior to the impoundment, on the average the water levels of Dongqing Lake and Poyang Lake are asked to fall down 4.44, 4.06, 3.63, or 4.51 m before May. This could be realized partly by the river and lakes themselves since the runoff of the river decreases and hence the lakes compensate it for the loss.

The lakes in the middle and lower reaches of the Yangtze play an crucial role in flood control, freshwater fisheries as well as reduction in the side-effect of the Three Gorges Project. Unfortunately, for many years most of the lakes have gradually been silting up or were reclaimed as croplands. For example, the formerly largest lake, Dongqing had an estimated maximum lake area of 14,000 km^2 during historical times. It was reduced to an area of about 6,000 km^2 in 1820, to 5,400 km^2 in 1890, to 4,360 km^2 in 1949, and to 1,840 km^2 in 1976. If effective measures are not taken, it will disappear entirely (Zhao, 1986, p. 129). For the sake of flood control, and freshwater fisheries as well as the future environment in the Yangtze System, all the lakes must be protected from diminishing.

5.3.4 Control of Disease and Weed Spread

The Three Gorges Reservoir will be located in an area of humid subtropical climate with the mean annual air temperature ranging from 16.5-19° C and the mean annual precipitation of about 1100 mm. At this point, the future project may induce some water-associated diseases and aquatic weeds to spread around and within the man-made lake respectively. Effective measures for dealing with such hazards have been demonstrated in many tropical and subtropical reservoirs.

A. Disease Control

Successful control of diseases are specific to local conditions and, as water-borne diseases are found world wide, several national and international agencies (such as WHO and FAO) have joined their efforts to eradicate them. Generally, at present, prevention techniques for improving water supplies and sanitation facilities would be most beneficial. The most successful measures used currently, however, consist of chemical extermination of the hosts of the diseases, thus reducing potential infection. In fact, these techniques and measures are classic. As early as in 1930's, the danger of outbreaks of malaria as a result of dam construction realized by the Tennessee Valley Authority was circumvented by shoreline sanitation, periodic water drawdowns, and insecticide application. In particular, periodic fluctuations in the water level can destroy the larvae of malaria-transmitting mosquitoes without side-effects.

Also, the control of reservoir-induced diseases depends heavily on the establishment of health services. At the present planning stage of the Three Gorges

Project, a responsible health institution should be established to deal with the area involved. A public health administrator-planner, assisted by advisers in the environmental fields of epidemiology, ecology, biology, sanitation, and any others that are required, would make comprehensive diagnosis of the situation and establish base lines, including a complete inventory of the existing health facilities.

B. Weed Control

The control of aquatic weeds is a difficult and expensive undertaking especially in tropical and subtropical conditions. Timely preventive measures are the most effective way to minimize weed invasion.

Some factors which in certain conditions contribute to the proliferation of aquatic weeds on impoundments have been identified. During the preparatory phase of dam projects, terrestrial plants in the area to be flooded may be cleared or left standing. Unless clearance involves the destruction of buds and seeds as well. existing aquatic species may still appear on the impoundment. If the vegetation is burnt and the ash flooded, the area may become sufficiently fertilized with nutrients to support an explosion of weed growth. If the plants are not cleared, they decay and enrich the water, especially in shallow areas, enabling aquatic plants to growth. Therefore, terrestrial plants in the area must be cleared and then moved away, with the destruction of their buds and seeds.

The elimination of shallow areas, either by pre-impoundment engineering measures or manipulation of the water height in the dam, can be an effective preventive measure. Additionally, appropriate handling of terrestrial plants will also reduce the chance of weed infection. Also, preventing water from being polluted with nutrient-rich sewage and with agricultural chemicals and fertilizers will contribute to weed control.

Mechanical clearing of weeds has been successful on small reservoirs; with careful planning and persistence, it also can be effective on large dams. In the long run, if combined with appropriated technology for weed utilization such as production of animal feed, mechanical removal of plants may prove to be one of the environmentally-sound measures for dealing with aquatic weeds (UNEP, 1977).

So far considerations have been provided for all the principal adverse environmental impacts of the particular large-scale water resource project on the Yangtze except the waterlogging and the reservoir-induced earthquakes. The waterlogging related to the system of perennial irrigation seems not to be a problem created by the project since it has no purpose for irrigation, and in the past, no evidence indicated that the area of the Three Gorges Reservoir is active in seismicity. Nevertheless, from the practical point of view, it is suggested that continuous geophysical observations should be made in the area where the big dam is planned. These measures should be started as soon as possible and should comprise the installation of a network of portable seismographs. Detailed geological and morphological studies should, of course, also be included. The record should be continued during the filling, and the combination of all information should eventually permit the necessary security measures to be undertaken.

CHAPTER VI

SUMMARY AND CONCLUSIONS

"The Three Gorges have been celebrated for many centuries in the literature of China and in the hearts of its people. But now, after decades of dreams, studies, plans and preparation, the government stands on the verge of approving this spectacular strip of river and mountain as the site for construction of the world's largest concrete dam. Meanwhile, critics of the project--who worry about cost, technical feasibility, silting and the massive relocation effect as well as damage to the environment and scenery--are taking on an air of near desperation, raising their pleas for top decision-makers to give critical views an impartial hearing" (Holley, 1988). Summing up the analyses done in the first five chapters, this closing chapter will present its own views.

6.1 SUMMARY

The Three Gorges Project will be constructed primarily for flood control, hydro-power production and waterway improvement, but at the expense of massive population displacement as well as other biological and physical effects. As a result of the great man-made lake, many people throughout China will share a profound sense of both pride and loss.

The dam will be of key importance to flood control. It could save tens or hundreds of thousands of lives by regulating the devastating flooding that can occur when heavy rains hit the upper reaches of the Yangtze, as has happened again and again over the centuries. Without the dam, according to officials of the Yangtze Valley Planning Office in Wuhan, a repetition of the 1870 rains could kill hundreds of thousands of people along the lower reaches of the river (Holley, 1988).

Even the proposed 150-m dam would be the biggest hydro-power producer in the world. It will be able to generate 66.7×10^9 kilowatts of electricity annually, 40% more than the capacity of Brazil's Itaipu Dam, now the world's largest hydro-electric producer. At this point, the project could transform the economy of Central-South China and East China by eliminating power shortages and create employment opportunities by promoting regional industrialization.

The turbulent river with hundreds of rapids, shoals and shallows could become a long, deep lake stretching about 500-700 km from the dam to the city of Chongqing. Barges with three times the tonnage of those now able to pass the gorges would be able to reach Chongqing, the largest metropolis of China with a total urban and nearby rural population of 14×10^6, thereby vastly increasing the access of the city and surrounding regions to world trade.

The adverse impacts of the project, however, particularly on the human society, would likewise be immense. Along the river, the homes, factories and farmland of between 333,000-768,000 people would be submerged, according to statistics of June 1986. All would need new houses, and many would need new jobs. Wanxian, a city with a population of 14,000, would be affected most; two-thirds of its area would be flooded (Holley, 1988).

Aquatic wildlife would be affected adversely too. Fish species of Chinese Sturgeon and Manli, two of seven migratory fish species in the Yangtze, could disappear above the dam due to the "barrier effect" of the dam. In addition, cold-water releases, which could do damage to fish downstream, could occur if any one of the three higher schemes is put into operation in the future.

The reservoir also creates siltation which reduces its own capacity, and far away, produces modification in sediment and the haline circulation within the coastal region. "Most reservoirs must be supplemented or replaced by the time they have lost 50% of their capacity" (Brown, 1950). Assuming this to be a criterion of useful life of a reservoir, the useful lives of the Three Gorges Reservoirs are estimated at 42.7, 51.4, 62.3 and 75.6 years for the 150-m, 160-m, 170-m and 180-m Storage Schemes respectively. The change of sediment supply to the estuary after the project operation will not be dramatic so that the reduced sediment supply seems capable of pushing the coast seaward continuously. During January to May, at most, salinity will be decreased by 0.81‰ at a given point where the initial salinity is 17‰; 3,814 m^3s^{-1} of sea water will be added to the estuary where the initial ratio of fresh/salt water is 1:2 due to greater fresh water release into the estuary. By contrast, during October and November, salinity could rise by 1.39‰ and 9,242 m^3s^{-1} of sea water would be decreased at the given points respectively because of the reduction in the fresh water supply to the estuary.

To contrast the selected major gains and losses of the project, a methodology of an Environmental Evaluation System (EES) was employed. The result is that the selected human, economic, biological and physical environmental quality will be improved in the 150-m, 160-m, 170-m or 180-m Storage Scheme, but the 150-m is the best.

Table 6-1. Recommendations for Treatment of the Three Gorges Project's Issues

Issue	Recommendation
Population displacement	1 Provision of some employment created by the project for the relocatees 2 Establishment of new settlements as a supplementary solution
"Barrier effect" and cold-water release	1 Application of fishway, collection and transportation facilities, and artificial spawning-grounds 2 Selected-depth release
Reservoir siltation	1 Sediment flushing every year 2 Venting during flood inflows
Coastal erosion and fresh/salt water alternation	1 Desiltation in the reservoir 2 Re-regulating discharge through the dam by the lakes downstream
Water-borne diseases	1 Shoreline sanitation, periodic water drawdowns and insecticide application 2 Establishment of health services
Aquatic weeds	1 Eradication of plants with the buds and seeds prior to the reservoir filling 2 Elimination of shallow areas, prevention the water from pollution and mechanical clearing of weeds if they spread
In general: giving most concerns to the hazard-concentrated area of the reservoir	

After investigation of universal implications of man-made lakes on a world-wide scale, careful consideration has been given to the principal issues arising from the proposed project, and a number of appropriate recommendations have been presented for tackling them as shown in Table 6-1.

6.2 CONCLUSIONS

Man, throwing a dam across a river to create a lake, brings prosperity to himself, but with a continuum of hazards since the river system is a discrete natural unit of the earth's surface. Environmental planning for large-scale water resource development projects must be directly towards allowing social and economic development to occur within the region without the excessive degradation of the human-resource system. "The natural resources of a river should be developed to increase the productiveness of the region but wherever possible development should be limited to that which can be supported by the river system without straining it too much. This concept is referred to as 'keep the system within its carrying capacity'" (Street, 1981).

Using this concept, the last question then arises of how much has been done by the Tennessee Valley Authority and by the Aswan High Dam in the past and how much will be done by the Three Gorges Project in the future to improve the overall carrying capacity of their own regions.

Brown (1983), in his article "Fifty Years of Operation of the TVA Reservoir System", said "the TVA system of dams makes the Tennessee River one of the most useful in the world". In addition to flood control, navigation, and hydro-power generation, the system is operated for recreation, fish and wildlife, municipal and industrial water needs, low flow augmentation, mosquito and aquatic plant control. Baxter (1977), of the Canada Centre for Inland Waters, Applied Research Division, stated "in our own time, such projects as the TVA have been rightly regarded as marvellous accomplishments". Doubtless, the TVA has made a great contribution to the overall carrying capacity of its region.

Fahim (1980, p. 39), an Egyptian anthropologist, said "the Aswan High Dam seems to have achieved its main goals in terms of water storage, hydro-electric power production, and riverflow control, thus providing Egypt with the potential for future agricultural and industrial development."

In 1972, the president of the American Society of Civil Engineering headed a professional American team to inspect the Aswan project on site. He expressed the view that "in the light of its (the dam's) benefits to a needy people, the so-called ecological effects appear to be nominal". He also appeared convinced that "detractors of this great project will do well to view it from the right end of their binoculars, in proper focus" (Wisely, 1972).

In 1976, the Polish ecologist Julian Rzoska reviewed the dam controversy and concluded that "the critics of the dam come from climatically and industrially far off countries, and must appreciate that Egyptians are aware of the dam's implications; their needs are great, and it is for them to ultimately decide how these should be met" (Rzoska, 1976).

In 1979, a former Egyptian Minister of Irrigation wrote that "Egypt's Aswan High Dam is bringing prosperity to the country but without the side effects so many feared". He also stressed the vital role the Aswan High Dam is playing and will continue to play in Egypt's economy. "Egyptians can still look forward to finding the source of their wealth in the River Nile; but they need no longer fear that it will also bring famine" (Abul-Atta, 1979).

Based on these different points of view, it seems that the statement, "now we will build new pyramids for the living," frequently made by the late President Nasser of Egypt, has come true, and the Aswan High Dam has improved the overall carrying capacity of the human, biological, and physical systems along the Nile although it has reduced the capacity in particular areas such as the Egyptian Mediterranean coast.

For the construction of the Three Gorges Dam, the Canadian International Development Agency sponsored a $14-million feasibility study, which was conducted by a consortium of Canadian engineering companies and utilities. "The study, released in Ottawa 14 February 1989, concludes that the environmental impact of the dam and flooding, and the relocation of 750,000 area residents to higher ground, are manageable. "It adds that there is no lower-cost alternative that could provide flood control and hydro-electric power" (Howard, 1989).

However, strong objections have been taken to the project. "Even the United States, the most scientifically and technically advanced country in the world, has never built a hydro-electric project of this magnitude," Qian Jiaju, an outspoken Chinese economist, cautioned in a May article published in the pro-Beijing Hong Kong newspaper Wen Hui Bao. He also concurred with a comment that he attributed to Zhou Peiyuan, a prominent physicist who has also criticized the proposal: "We cannot fully predict the impact on society and the environment. Should something unexpected go wrong, we would leave an incalculable legacy of troubles to future generations" (Holley, 1988). Nevertheless, the evaluation in Chapter IV suggests that the Three Gorges Project would not reduce the overall carrying capacity of the Yangtze System at all.

Table 6-2 Comparing Impacts of the Aswan Project and the Three Gorges Project

Impact	Description	
	Aswan Project	Three Gorges Project
Population displacement	100,000	330,000-768,000
Reservoir sediment trap efficiency during the first ten years	89.12%	61.13-76.23%
Water-borne disease spread	Reservoir area and downstream	Reservoir area
Ratio between sediment supply to estuaries before and during the first ten years of reservoir operation	10.12%	Over 50%
Reduction in freshwater supply to estuaries annually	very much	no
Fish destruction	Loss of sardines along the coast	Loss of Chinese Sturgeon and Manli upstream of the dam and damage of cold-water release
*	* * *	
Flood controlled	Over one-in-a-thousand-year floods	About one-in-a-thousand-year floods
Annual hydro-power production (million kwh)	5-8	66.7-89.1
Navigation	Regulating high and low runoff downstream	Tripling tonnage of barges within the Three Gorges
Irrigation	Creating perennial irrigation of 973,000 acres and reclaiming land of 946,600 acres	no

Relatively speaking, the Three Gorges Project may not be comparable with the

TVA, but rather with the Aswan High Dam in terms of achievement (Table 6-2). "In retrospect, the Aswan Dam Project seems to have made political history and has become a vital economic milestone in national development plans and aspirations" (Fahim, 1980, p. 25). Looked at positively and constructively, as long as the massive population displacement can be accomplished successfully, the Three Gorges Project should be developed soon for the survival and progress of the Yangtze's middle and lower reaches as well as for the whole country.

REFERENCES

1. Abul-Atta, A. A., 1979. After the Aswan. ***Mazingria***. London Pergamon Press, No. 11.
2. Baxter, R. M., 1977. Environmental Effects of Dams and Impoundments. ***Annual Review of Ecology and Systematics***, 8, 255-283.
3. Biswas, A. K., 1978. United Nations Water Conference: Summary and Main Document. ***Water Development, Supply and Management***, Vol. 2. Pergamon Press, Oxford, England, UK: XVII + 217 Pp.
4. Brown, B. W. & Shelton, R. A., 1983. Fifty Years of Operation of the TVA Reservoir System. ***Accomplishments and Impacts of Reservoirs*** (Eds. Green, G. G. & Eiker, E. E.). American Society of Civil Engineers, P. 138-151.
5. Brown, C. B., 1944. Sedimentation in Reservoirs. ***Transactions of the American Society of Civil Engineers***, 109, 1085.
6. Brown, C. B., 1950. Sediment Transportation. In: H. Rouse (Editor), ***Engineering Hydraulics***, Wiley, New York, N. Y., P. 826-832.
7. Brune, G. M., 1953. Trap Efficiency of Reservoirs. ***Transactions of Geographical Union***, 34 (3), 407-418.
8. Buttling, S. & Shaw, T. L., 1973. Predicting the Rate and Patterns of Storage Loss in Reservoirs, P. 565-580 in ***Translations of the Eleventh International Congress of Large Dams***, Madrid, Spain. Vol. 1, International Commission on Large Dams, Paris, XXXViii + 974 Pp., Illustration.
9. Chen, X. Y., 1986. Significance of Construction of the Three Gorges Project in the Power Development in China. ***People's Yangtze River***, No. 2, 1986, 8-13.
10. Chen, Z. M., 1986. The Impacts of the Three Gorges Project on the Environment. ***People's Yangtze River***, No. ?, 1986, 9-14.
11. Congress, 1935. ***Act of Congress***, Publication NO. 17-73D. US Government Printing Office, Washington.
12. Cramer, F. K. & Oligher, R. C., 1964. Passing Fish through Hydraulic Turbines. ***Transactions of the American Fisheries Society***, 93, 243-259.
13. Dee, N., Baker, J., Drobny, N., Duke, K., Whitman, I. & Fahringer, D., 1973. An Environmental Evaluation System for Water Resources Planning. ***Water Resources Research***, Vol. 9, No. 3, 523-535.
14. Dendy, J. S. & Strout, R. H., 1949. The Dominating Influence of Frotana Reservoirs On Temperature and Oxygen in the Little Tennessee River and Its Impoundments. ***Journal of the Tennessee Academy of Science***, 24, 41-51.
15. Din, S. H. Sharaf, 1977. Effects of the Aswan High Dam on the Nile Flood of the Estuarine and Coastal Circulation Pattern along the Mediterranean Egyptian Coast. ***Limnology and Oceanography***, 2 (2), 194-207.

16. Ebel, W. J. & Raymond, H. L., 1976. Effect of Atmospheric Gas Saturation on Salmon and Steelhead Trout on the Snake and Columbia Rivers. ***Marine Fisheries Review***, 38(7), 1-14.

17. Elliott, C., 1981. Forward. ***River Basin Planning: Theory and Practice***. (Eds. S. K. Saha & C. J. Barrow). John Wiley and Sons, P. XI-XIII.

18. EOPYR (the Editorial Office of ***People's Yangtze River***), 1986. Introduction to the Three Gorges Project on the Yangtze River. ***People's Yangtze River***, No. 1, 1986, 24-30.

19. Fahim, H. M., 1981. ***Dam, People and Development: the High Aswan Dam Case***. Pergamon Press.

20. Fraser, J. C., 1972. Regulated Discharge and the Stream Environment. Pp. 26-85 in the ***Ecology and Men*** (Eds. R. R. Oglesby, C. A. Carlson & J. A. McCann). Academic Press, New York, XVII + 465 Pp., Illustration.

21. Frickel, D. G., 1972. Hydrology and the Effects of Conservation Structures, Willow Creek Basin, Valley Connty, Montana, 1954-1968. ***US Geological Survey Water Supply Paper***, 1532-G, 35 Pp., Illustration.

22. Geen, G. H., 1974. Effects of Hydroelectric Development in Western Canada on Aquatic Ecosystems. ***Journal of the Fisheries Research Board of Canada***, 31, 913-927.

23. Gibbons, D. C., 1986. Navigation. ***The Economic Value of Water***. Resource for the Future, Inc., P. 74-85.

24. Gill, M. A, 1968. River-Bed Degradation below Dams. Proceedings of the American Society of Civil Engineers, ***Journal of the Hydraulics Division***, Hy2, 593-595.

25. Gill, M. A., 1979. Sedimentation and Useful Life of Reservoirs. ***Journal of Hydrology***, Vol. 44, 89-95.

26. Gill, M. A., 1988. Planning the Useful Life of a Reservoir. ***Water Power & Dam Construction***, May 1988, 46-47.

27. Gore, J. A., 197?. Reservoir Manipulations and Loenthic Macroinvertebrates in a Prairie River. ***Hydrobiologia***, 55, 113-123.

28. Greenhalgh, G., 1980. ***The Necessity for Nuclear Power***. Graham & Trotman, London: XI + 250 Pp., Illustration.

29. Gvelesiani, L. G. & Shmalkmzel, N. P., 1971. Studies of Storage Work Silting of H. E. P. Plants on Mountain Rivers and Silt Deposition Fighting. ***International Association of Hydraulic Research***, 14th Congress, Vol. 5, 17-20.

30. Hafez, M. & Shenouda, W. K., 1977. The Environmental Impacts Of the Aswan High Dam. ***Water Development and Management***, March 1977, Part 4, 1777-1785. Pergamon Press.

31. Hamdan, G., 1961. Evolution of Irrigation Agriculture in Egypt. ***A History of Land Use in Arid Region*** (Ed. L. D. Stamp). UNESCO, Paris, P. 119-142.

32. Hazan, A., 1914. Storage to B^ Provided in Impounding Reservoirs for Municipal Water Supply. ***Transactions of the American Society of Civil Engineers***, 77, 1539-1540.

33. Heikal, H., 1973. The Cairo Documents. ***Garden City***. N. Y., Doubleday, P. 62.

34. Hirsch, A. M., 1959. Water Legislation in the Middle East. ***American Journal of Comparative Law***, 8, 168.

35. Holden, P. B. & Stalnaker, C. B., 1975. Distribution and Abundance of Mainstream Fishes of the Middle and Upper Colorado River Basins, 1967-1973. ***Translation of the American Fisheries Society***, 104 (2), 217-231.

36. Holley, D. (Los Angeles Times), 1988. Massive Power Dam Will Flood One of China's Natural Wonders. ***Kitchener-Waterloo Record***, Tues., Sept. 13, 1988, A7.

37. Howard, R., 1989. Canadian Study Backs Proposal for Controversial Dam in China. ***The Globe and Mail***, February 15, 1989, A3.

38. Hsieh, C. M., 1973. Mining and Manufacture. ***Atlas of China***. Mcgraw-Hill Book Company, P. 95-110.

39. Hu, X. X., 1986. Preliminary Investigation on Issues Concerning the Impact of the Three Gorges Project Construction on the Aquaculture of the Yangtze. ***People's Yangtze River***, No. 7, 1986, 17-21.

40. IG (Institute of Geography, USSR Academy of Sciences), 1969. ***The Physical Geography of China***. Frederick A. Praeger, Inc., Publishers.

41. Jones, J. O., 1954. TuKiangYien: China's Ancient Irrigation System. ***Geographical Review***, 44, 543-559.

42. Kalitsi, E. A. K., 1973. Volta Lake in Relation to the Human Population and Some Issues in Economics and Management. ***Man-Made Lakes: Their Problems and Effects*** (Eds. W. C. Ackermann, G. F. White, E. B., Worthington, & J. L. Ivens). American Geographical Union, P. 77-86.

43. Lane, E. W. & Koelzer, V. A., 1953. ***Density of Sediments Deposited in Reservoirs***. Report No. 9, St. Paul, US Engineering District.

44. Lightfoot, R. P., 1979. Planning Reservoir-Related Resettlement Programmes in Northeast Thailand. ***Journal of Tropical Geography***. Vol. 48, 47-57.

45. Long, G. E. & Krema, R. F., 1969. Research on a System for Bypassing Juvenile Salmon and Trout around Low-Head Dams. ***Commercial Fishing Review***, 31 (6), 27-29.

46. Lou, Y. M., 1988. Reforming, Opening and Accelerating Water Power Development. ***People's Daily*** (Oversea Edition), 24th Feb. 1988, P. 3.

47. Mackinnon, D., Edgeworh, L. & Mclaren, R. E., 1961. An Assessment of Jones Creek Spawning Channel. ***Canadian Fish Culturist***, 30, 25-31.

48. Mickey, W. V., 1973. Reservoir Seismic Effects. ***Man-Made Lakes: Their Problems and Effects*** (Eds. W. C. Ackermann, G. F. White, E. B. Worthington, & J. L. Ivens). American Geographical Union, P. 472-482.

49. Manohar, M., 1975. Dynamic Factors Affecting the Nile Delta Coasts. ***Seminar Nile Delta Sediment.*** 25-29 October 1975. Arab Rep. Egypt. Acad. Sci. Res. UNDP Coastal Erosion Studies.

50. Mullen, J. W., Starostka, V. J., Stone. J. L., Wiley, R. W., & Wiltzius, W. J., 1976. Factors Affecting Upper Colorado River Reservoir Tailwater Trout Fisheries. Pp. 405-423 in ***Instream Flow Needs***, Vol. II (Eds. J. F. Orsborn & C. E. Allman). American Fisheries Society, Bethesda, Maryland, USA: 657 Pp., Illustration.

51. Mundie, J. H., 1979. Optimization of the Salmonid Nursery Stream. ***Journal of the Fisheries Research Board of Canada***, 31, 1827-1837.

52. Neu, H. J. A., 1975. Runoff Regulation and Its Effects on the Ocean Environment. ***Canadian Journal of Civil Engineering***, 2, 583-591.

53. Owen, M., 1973. The People's and Their Local Governments. ***The Tennessee Valley Authority.*** Praeger Publishers, Inc., P. 216-233.

54. Pasch, R. W., Hackney, P. A. & Holbrook, J. A. II, 1980. Ecology of Paddlefish in Old Hickory Reservoir, Tennessee, with Emphasis on First-Year Life History. ***Transactions of American Fisheries Society***, 109 (2), 157-167.

55. Paul, T. C. & Dhillion, G. S., 1988. Sluice Dimensioning for Desilting Reservoirs. ***Water Power & Dam Construction***, May 1988, 40-44.

56. Petts, G. E., 1984. ***Impounded Rivers: Perspectives for Ecological Management.*** John Wiley & Sons Ltd.

57. Qian, N., Zhang, R., & Chen, Y. C., 1986. Sediment Problems of the Three Gorges Project on the Yangtze. ***People's Yangtze River***, No. 11, 1986, 1-15.

58. Rausch, D. L. & Heinemann, H. G., 1975. Controlling Trap Efficiency ***Transactions of the American Society of Agricultural Engineers***, 18(6), 1105-1113.

59. Rondinelli, D., 1985. ***Applied Methods of Regional Analysis: the Spatial Dimensions of Development Policy.*** Westview Press, Inc., P. 56.

60. Rothé, J. P., 1973. Summary: Geophysical Report. ***Man-Made Lakes: Their Problems and Effects*** (Eds. W. C. Ackermann, G. F. White, E. B. Worthington, & J. L. Ivens). American Geographical Union, P. 441-454.

61. Ruddle, K. & Rondinelli, D., 1983. ***Transforming Natural Resources for Human Development: A Resource System Approach to Development Policy.*** Tokyo: United Nations University Press.

62. Rzoska, J., 1976. A Controversy Reviewed. ***Nature***, Vol. 261, No. 5560.

63. Saha, S. K., 1981. River Basin Planning as a Field of Study: Design of a Course Structure for Practitioners. ***River Basin Planning: Theory and Practice*** (Eds. S. K. Saha & C. J. Barrow). Jones Wiley and Sons, P. 1-40.

64. Scheoneman, D. E. & Junge, C. D., 1961. An Evaluation of the Mortalities to Downstream Migrant Salmon at Mcnary Dam. ***Transactions of the American Fisheries Society***, 90, 58-72.

65. Street, E., 1981. The Role of Electricity in the Tennessee Valley Authority. ***River Basin Planning: Theory and Practice***. (Eds. S. K. Saha & C. J. Barrow). John Wiley and Sons, P. 233-252.

66. Sutcliffe, W. H., 1972. Some Relations of Land Drainage, Nutrients, Particulate Material, and Fish Catch in Two Eastern Canadian Bays. ***Journal of the Fisheries Research Board of Canada***, 29, (4).

67. Sutcliffe, W. H., 1973. Correlations between Seasonal River Discharge and Local Landings of American Lobster (Homarus Americanus) and Atlantic Halibut (Hoppoglossus Hippoglossus) in the Gulf of St. Lawrence. ***Journal of the Fisheries Research Board of Canada***, 30, (6).

68. Takes, C. A. P., 1973. Resettlement of People from Dam Reservoir Areas. ***Man-Made Lakes: Their Problems and Effects*** (Eds. W. C. Ackermann, G. F. White, E. B. Worthington, & J. L. Ivens). American Geographical Union, P. 720-725.

69. Trautman, M. B., & Gartman, D. K., 1974. Re-Evaluation of the Effects Man-Made Modification on Gordon Creek between 1887 and 1973 and Especially as Regards Fish Fauna. ***Ohio Journal of Science***, 74(3), 162-173.

70. Trefethen, P., 1972. Man's Impacts on the Columbia River. P. 77-98 in ***River Ecology and Man*** (Eds. R. T. Oglesby, C. A. Carlson & J. A. McCann). Academic Press, New York, USA: XVII + 465 Pp., Illustration.

71. UNEP (United Nations Environment Programme), 1977. Environmental Issues in River Basin Development. ***Water Development and Management***, Part 3, March 1977 Pergamon Press, P. 1163-1173.

72. Waddy, B. B., 1973. Health Problems of Lakes: Anticipation and Realization, Kainji, Nigeria, and Kossou, Ivroy Coast. ***Man-Made Lakes: Their Problems and Effects*** (Eds. W. C. Ackermann, G. F. White, E. B. Worthington, & J. L. Ivens). American Geographical Union, P. 765-768.

73. Walling, D. E., 1981. Yellow River Which Never Runs Clear. ***The Geographical Magazine***, LIII (9), 568-576.

74. Wisely, W. H., 1972. People, Ecology, and the Aswan High Dam. ***Civil Engineering***, Vol. 52.

75. Worthington, E. B., 1972. The Nile Catchment Area-Technological Change and Aquatic Biology. ***The Careless Technology: Ecology and International Development*** (Eds. M. T. Farvar & J. P. Milton). Doubleday and CO., New York, P. 189-205.

76. Xu, G. J. & Peng, D. M., 1986. Flood Control Effect of the Three Gorges Project on the Yangtze River. ***People's Yangtze River,*** No. 1, 1986, 3-9.

77. Yao, B. H., 1986. Developing the Reservoir Region to Settle Displaced Persons Nearby: Preliminary Discussion on the Problem of Migration. ***People's Yangtze River,*** No. 3, 1986, 1-6.

78. Yao, L. Q., 1986. The Three Gorges Project and the Navigation on the Yangtze River. ***People's Yangtze River,*** No. 2, 1986, 1-7.

79. Zhao, S. Q., 1986. ***Physical Geography of China***. Science Press, & John Willey and Sons.